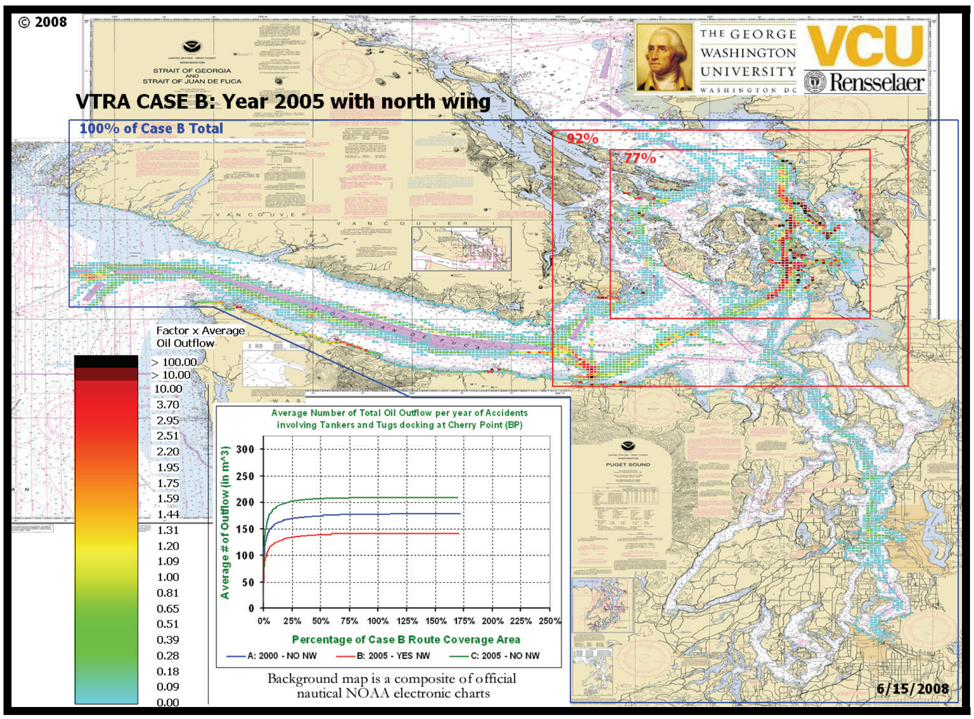
TECHNICAL APPENDIX A:
DATABASE CONSTRUCTION AND ANALYSIS



Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington

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Appendix A: Database Construction and Analysis

In order to develop accident and incident frequencies as input to the BP Puget Sound Vessel Traffic Risk Assessment (VTRA) maritime simulation, an analysis of maritime accidents and incidents in Puget Sound from 1995-2005 was undertaken. Accident and incident records for the time period and for the geographic scope of the project were solicited, and an accident-incident database was constructed. The data were analyzed, and the results of that analysis are presented in this report.

A-1. The Puget Sound VTRA Accident-Incident Database

The Puget Sound VTRA accident-incident database is comprised of maritime accident, incident, and unusual event records for tank, tug-barge, cargo, ferry, and fishing vessels over 20 gross tons underway or at anchor, for the years 1995-2005 in Puget Sound, in the State of Washington. The database takes the form of multiple Microsoft EXCEL spreadsheets (Table A-1) with a common format describing various accidents and incidents. The database is the compilation of all accidents, incidents, and unusual events gathered from the project's sources, filtered to include only those relevant records for the waterways of Puget Sound.

Table A-1. Database Files

Tanker Accidents and Incidents
Tug and Barge Accidents and Incidents
Cargo Accidents and Incidents (Public, Freighter, Bulk Carrier, Container, and Passenger Vessel)
WSF (Washington State Ferries) Accidents and Incidents
Fishing Vessel Accidents and Incidents
Unusual Events
Personnel Casualties

The geographic scope of the VTRA project, and of the events recorded in the database, include those listed in Table A-2: the Strait of Georgia (Ferndale southward), Rosario Strait, Haro Strait/Boundary Pass, Guemes Channel, Saddlebag, Puget Sound, and Strait of Juan de Fuca (west to 8 miles west of Buoy "J").

Table A-2. Geographic Locations in Puget Sound VTRA Accident-Incident Database

Location ID	Region Name
1	West Strait of Juan de Fuca
2	East Strait of Juan de Fuca
3	North Puget Sound
4	South Puget Sound
5	Haro Strait/Boundary Pass
6	Rosario Strait
7	Guemes Channel
8	Saddlebag
9	Strait of Georgia/Cherry Point
10	San Juan Islands

Three types of events are captured in the database: accidents, incidents and unusual events.

> *Accidents* are defined as occurrences that cause damage to vessels, facilities, or personnel, such as collisions, allisions, groundings, pollution, fires, explosions, or capsizing/sinking, but do not include personnel casualties alone.
>
> *Incidents* are defined as undesirable events related to control or system failures which can be detected or corrected in time to prevent accidents; incidents can also be prevented from developing into accidents by the presence of redundant or back up systems. Examples of incidents include propulsion failures, steering failures, navigational equipment failures, electrical equipment failures, structural damage or failure, and near misses.
>
> *Unusual events* are defined as events of interest to the safety of navigation that are deemed to be unusual by a participant or a reporting organization. In the database, unusual events were provided by the U.S. Coast Guard Vessel Traffic Services (VTS), U.S. Coast Guard Sector Seattle, U.S. Coast Guard Headquarters (MSIS and MISLE data), the Puget Sound Pilot Commission, British Petroleum (Cherry Point), and the Washington State Department of Ecology.

A-2. VTRA Accident-Incident Database Development

Marine casualty and incident data were gathered between June 2006 and June 2007 from the maritime organizations listed in Table A-3. Relevant data were defined as records that fell within the geographic area of study, within the timeframe 1 January 1995 to 31 December 2005, for a vessel greater than 20 gross long tons. Once the data were organized into a common data format, each of the resulting 2705 records was cross-validated with additional data sources to confirm the information in each record. This step was important to establish the accuracy and credibility of the data records and of the resulting database. Each record was assigned a location identification number, following Table A-2, and additional vessel characteristics were obtained from proprietary and open source databases. Once the records were complete, they were analyzed, and the results reported in this document.

Table A-3. Puget Sound VTRA Accident-Incident Database Contributors (Steward, 2007)

United States Coast Guard Headquarters
United States Coast Guard Sector Seattle
United States Coast Guard Sector Portland
United States Coast Guard Vessel Traffic Service Seattle
United States Coast Guard Marine Incident Database (Online)
Washington State Department of Ecology
Lloyd's List Marine Intelligence Unit Portal (Online)
Crowley Maritime Corporation
British Petroleum, Cherry Point Facility
Puget Sound Pilot Commission
Washington State Ferries
Seattle Post – Intelligencer
San Juan Islander

The main source for vessel characteristics in the VTRA database was Lloyd's Marine Intelligence Unit. For tanker vessels, the Clarkson Register was used to identify vessel owner evolution, important because of vessel and industry changes over the time period (1995-2005). Vessels were researched to identify the vessels' gross tonnage (long tons), its flag at the time of the casualty event, the owner at the time of the casualty event, the classification society at the time of the casualty event, its hull type, and vessel type. Records were separated into the following categories: Tanker Accidents and Incidents, Tug and Barge Accidents and Incidents, Cargo (Public, Freighter, Bulk Carrier, Container, and Passenger Vessel) Accidents and Incidents, WSF (Washington State Ferries) Accidents and Incidents, and Fishing Accident and Incidents.

A-3. Challenges with Accident, Incident and Human Factors Data

Accident and Incident Data

Problems with data to support modeling and analysis in marine transportation are well-documented (National Research Council, 1983; 1990; 1994; 2003). Data challenges in marine transportation have grown with the proliferation of electronic data, as the data have a varying storage requirements, exist in various formats, are gathered and collected from various agencies and individuals, with varying degrees of compatibility (National Research Council, 2003). As a result, data validation, compatibility, integration and harmonization are increasingly significant challenges in maritime data and risk assessments. In addition, no standard reliable database for near-miss reporting or exposure data has been developed in marine transportation, although the United States General Accounting Office, Congress and the National Academies/National Research Council have been exploring methods to improve the collection, representation, integration and sharing of accident and incident data (National Research Council, 1994; U.S. Department of Homeland Security, 2005; Transportation Research Board, 2008).

Impact of Data Challenges on Puget Sound VTRA Accident-Incident Database

In marine transportation, as in other domains, event analyses are constrained by the quality of the data gathered, the maturity of the associated reporting system, and the training and background of the investigator and reporter (who may not be the same person). Such constraints place limits on the adequacy and strength of analyses conducted with maritime safety data. These limitations have been characterized and analyzed extensively in reports prepared by the National Academies/National Research Council, the National Transportation Safety Board, and the U.S. General Accounting Office (National Research Council, 1990; 1994; 1999; 2003; National Transportation Safety Board, 1994).

The data records that comprised the VTRA accident-incident database required a significant amount of reconciliation and cross-validation across data sources to ensure that the records were accurate, that they captured the entire event of record, and to reduce redundancy in the final database. Reconciliation and cross-validation was particularly challenging, as the data records from one agency might capture the initial part of an event of record (e.g., an initiating mechanical failure), while the data records from another reporting agency, describing the same event, might capture the initiating event as well as the series of cascading and related events (e.g., other mechanical failures, an eventual accident).

Absent a standard incident and accident coding scheme, common data storage and transmission formats, and a common data dictionary defining accidents, incidents, unusual events and contributory situations, database construction and data record reconciliation encompassed several time-consuming steps: review of all available paper and electronic sources, additional search in many cases to confirm the events, and requests for additional information to ensure that the entire event was captured in the database. Resolution of open items in the database required search and compilation of data sources from maritime safety sources, as well as from vessel, traffic, transit, meteorological, charting and geographic information, as from the sources listed in Table A-4. This required retrieval of archival records from local (Puget Sound), state (Washington State), national (U.S. government) and international (Lloyd's List, Equasis, Clarkson's Register) sources, for several thousand events.

The lack of a standard event coding scheme had impact on the quality of the data collected, as discussed in the following section. For instance, the Coast Guard's MISLE database uses a pre-determined data set (a data dictionary) from which to classify events. Pre-MISLE data dictionaries included more detailed narratives that permitted descriptive root cause analyses, and other current classification schemes, such as that of the Pacific States-British Columbia Task Force (Pacific States/British Columbia Oil Spill Task Force, 1995; 1997; 2007), provide other descriptive classification schemes. Since the data collected at the time of a given event are in large part determined by the questions posed during the evidence gathering process and the data sets used to categorize the events, a standard and comprehensive data dictionary from which to classify and describe events is an essential element of a well-developed safety information system. As will be seen in the following section, the lack of a standard descriptive data dictionary used by all data-gathering organizations to codify events, as well as the lack of international data storage and transmission standards used by federal, state, local and private organizations to capture maritime safety data, occasioned an enormous amount of integration, reconciliation and verification effort during the VTRA accident-incident database construction.

A-4. Data Sources

A variety of organizations provided data as input to the event database, as seen in Table A-4. Since each of these source files was in different formats, of different sizes, and captured different views of safety performance in the Puget Sound marine transportation system, each of the data files was deconstructed, normalized, and integrated into a common database format, utilizing a common data definition language, based on the Pacific States-British Columbia Oil Spill Task Force data dictionary (1995; 1997; 2007). Table A-4 lists the data files received, the size of each of the files received, and the numbers of records received. 97 different data files, comprising over 3.8M records, and more than 1800 megabytes of data were received from 9 organizations as input to the database.

Table A-4 Puget Sound VTRA Accident Incident Database Source Files

Source	Type of Data	Size	# Records
USCG Group Seattle VTS	Incident Reports 2001	964k	54
	Incident Reports 2003	3.64M	20
	Old' Incident Reports	185k	50
	Incident Reports -- Access database	1.3M	646
USCG Website	Marine Casualty Causal Factor Table	751K	2747
	Marine Casualty Collision and Grounding Table	55K	209
	Marine Casualty Event Table	612K	2391
	Marine Casualty Flooding and Capsizing Table	84K	98
	Marine Casualty Fire and Explosion Table	32K	51
	Marine Casualty Facility Supplement Table	307K	869
	Marine Casualty and Pollution Master Table	8.11M	5965
	Marine Casualty Vessel Supplement Table	2.10M	4816
	Marine Casualty Personnel Injury & Death Table	167K	257
	Marine Pollution Substance Table	831K	3096
	Marine Casualty Structure Failure Table	26K	39
	Marine Casualty Weather Supplement Record	88K	68
	Facility Identification Table	8.05M	36980
	Vessel Identification Table	376.06M	>65536
USCG Sector Seattle	Spill Data from 2000-2006	694K	3204
USCG HQ	Closed Incident Investigation reports	8.1M	12,065
	Vessel Identification Table 2001 (vidt.txt)	112.165M	509805
	Facility Identification Table 2001 (fidt.txt)	5.106M	36980
USCG HQ	Marine Casualty and Pollution Master Table (cirt.txt)	56.848M	187812

Source	Type of Data	Size	# Records
	Marine Casualty Vessel Supplement Table (civt.txt)	14.688M	155781
	Marine Casualty Facility Supplement Table (cift.txt)	4.613M	51400
	Marine Casualty Event Table (cevt.txt)	5.724M	108927
	Marine Casualty Causal Factor Table (ccft.txt)	7.199M	116864
	Marine Casualty Collision and Grounding Table (ccgt.txt)	1.073M	26178
	Marine Casualty Structural Failure Table (csft.txt)	101K	2385
	Marine Casualty Flooding and Capsizing Table (cfct.txt)	867K	7677
	Marine Pollution Substance Table (cpdt.txt)	6.589M	84167
	Marine Casualty Personnel Injury Table (cpct.txt)	2.907M	15961
	Marine Casualty Fire and Explosion Table (cfet.txt)	272K	2339
	Marine Casualty Weather Supplement Record (cwxt.txt)	968K	7133
	Pollution Master Table (prit.txt)	11.699M	64421
	Pollution Vessel Supplement Record (pvst.txt)	3.477M	28669
	Pollution Facility Supplement Record (post.txt)	5.157M	36329
	Pre-MIN Pollution Substance Table (psst.txt)	4.922M	66686
	Pollution Substance Table (converta.txt)	18.219M	172683
	Ticket Investigation Master Table (prittk.txt)	2.503M	23434
	Ticket investigation Marine Violation Table (mvcttk.txt)	3.023M	23434
	Ticket Investigation Report Table (mtkt.txt)	2.639M	23434
	Ticket Investigation Casualty Event Table (tcet.txt)	1.714M	22286
	Marine Pollution Substance Table (pssttk.txt)	1.523M	21761
	Personnel Injuries/Deaths (pcas.txt)	3.601M	20752
	Vessel Casualties (vcas.txt)	15.721M	68592
	Master Pollution table (mpir70.txt)	15.79M	98447
	Master Pollution Table (mpir80.txt)	22.269M	127967
	Coast Guard Response Table (mprc70.txt)	667K	6970
	Coast Guard Response Table (mprc80.txt	11.008M	111633
	Non-Coast Guard Response Table (mprn70.txt)	636K	17589
	Non-Coast Guard Response Table (mprn80.txt)	1.308M	33028
	Marine Pollution Facility Table (mpsf70.txt)	3.678M	69921
	Marine Pollution Facility Table (mpsf80.txt)	2.453M	83120
	Marine Pollution Vessel Table (mpsv70.txt)	955K	28527
	Marine Pollution Vessel Table (mpsv80.txt)	1.504M	44580
	Marine Pollution Substance Table (mtl70.txt)	7.499M	98448
	Marine Pollution Substance Table (mtl80.txt)	10.001M	129751
	Marine Violation Table (mv70.txt)	1.664M	32761
	Marine Violation Table (mv80.txt)	3.362M	52635
Washington State Ferry Project	Puget_Sound_VTS_Unusual_Incident_tblUI	548K	1747
	Puget_Sound_VTS_Unusual_Incident_byTypeCode		19
	Puget_Sound_VTS_Unusual_Incident_byVessels		1497
	washdata,_7_Aug_1998/DIM(Sarmis)	269K	30
	washdata,_7_Aug_1998/Waterway		455
Washington State DOE	Multi PDF files	N/A	7
Puget Sound Pilot Commission	Puget Sound Pilot Commission Incident Data	69K	64

Source	Type of Data	Size	# Records
Washington State Dept of Ecology	Washington State Resource Damage Assessment by Date	60K	395
	Past Incidents of Interest	1.03M	10
US Coast Guard Headquarters	Complete accident/incident data up to 2006.		
	Same as data on 08/18/2006(CD1)	370M	
	MisleActivity.txt	3.122M	24970
	MisleFacEvents.txt	1.149M	5708
	MisleFacility.txt	9.159M	40,374
	MisleFacPoll.txt	2.363M	4653
	MisleInjury.txt	435K	3053
	MisleOtherPoll.txt	2.093M	4246
	MisleReadme.doc	69K	
	MisleVessel.txt	382.470M	858,081
	MisleVslEvents.txt	5.059M	23765
	MisleVslPoll.txt	3.429M	6491
British Petroleum	Accident/Incident report in email format (transfer to PDF and saved)	197K	
DOE	Accident/Incident Data		
	Incidents_CPS_1994_present(Center Puget Sound)	304K	718
	Incidents_NPS_Consolidated_Grabowski(North Puget Sound)	234K	426
	Incidents_SPS_1994_present_Grabowski(South Puget Sound)	15K	4
Lloyd's MIU Portal	Vessel Casualty Information	N/A	2
USCG Seattle	Anchoring Database	1,124K	5614
USCG Portland	Portland MSIS & MISLE Data	1551K	4256
USCG Seattle	Intervention and Near Misses(Including Audio files)	225M	25
Washington State DOE	Central and South Puget Sound Accident Files	315K	46
	CPS_all,_9_Feb_2007	1815K	420
	CPS_casualty,_9_Feb_2007	197K	37
	CPS_near_miss,_9_Feb_2007	1064K	226
	CPS_spills,_9_Feb_2007	46K	4
	SPS_all,_9_Feb_2007	95K	90

Because of the large number of records and their various sources, it was necessary to track both the original source of each record and any redundant records from different sources. This information was tracked in the field "event cross-validated" in the database as new, incoming records were inserted and checked for repeats. Figure A-1 provides a breakdown of the various data sources for the events in the VTRA accident-incident database.

The Challenge of Integrating Multiple Data Sources

The development of the Puget Sound VTRA accident-incident database highlighted the complexities inherent in integrating multiple data sources into a coherent information system. One difficulty lay in categorizing the types of events in the database, and in determining whether a series of events that occurred together were incidents or accidents. If an event resulted in an incident (propulsion failure, steering failure, navigation equipment failure, etc.), it was categorized as an incident. If the event resulted in an accident, it was categorized as an accident, and the precipitating incidents or cascading events associated with the accident were captured in the narrative portion of the database.

Another difficulty was occasioned by the varying information contained in the different data sources, which necessitated merging several databases into one accident-incident repository. For instance, of the 2705 events records in the database, 1759 (65%) of the records were unique to USCG records, 478 (17.67%) were unique to Washington DOE, with only 377 (13.94%) represented in both the USCG and DOE databases, as seen in Figure A-1 and Table A-5. Thus, in order to build a comprehensive accident-incident database, both data sets were required. The Coast Guard and Washington Department of Ecology are both charged with maritime data collection, analysis and reporting responsibilities within the Puget Sound marine transportation system; in order to determine the differences in the data sets between two organizations, additional analysis was undertaken, as described in the next section.

Figure A-1 Puget Sound Accident – Incident Data Sources

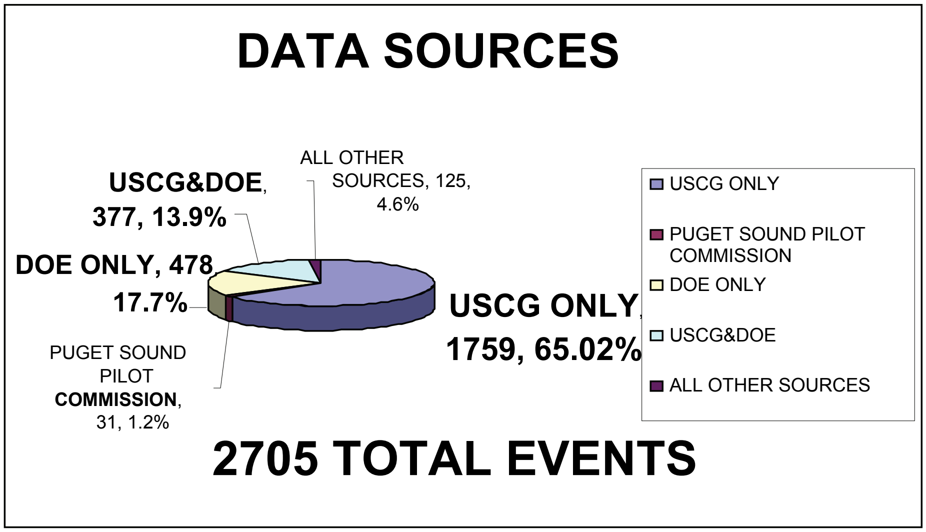

Table A-5 Puget Sound VTRA Accident-Incident Data Sources

Source	Events	% of Events	Accidents	Incidents
USCG only	1759	65.02%	1074 (73.46%)	631 (54.44%)
Wash DOE only	478	17.67%	148 (10.12%)	324 (27.96%)
WSF only	17	6.3%	7	5
Pilots only	31	1.15%	14	3
BP only	4	0.15%	0	3
USCG/DOE	377	13.94%	193 (13.2%)	184 (15.88%)
USCG/WSF	5	0.2%	5	0
USCG/Pilots	4	0.1%	4	0
Pilots/DOE	11	0.41%	7	2
DOE/USCG/Pilots	6	0.22%	5	1
DOE/Seattle Anchor Log	2	007%	0	2
USCG/DOE/WSF	2	0.07%	1	1
Other	9	0.33%	4	3
Total	2705	100%	1462	1159

Other data sources: Seattle P-I, San Juan Islander, Lloyd's List, EQUASIS database, Crowley, Washington Dept of Ecology text, accident files, CG Sector Seattle anchoring log/ database; CG Sector Seattle Watch Supervisor's Log, etc.

Differences between Key Data Sources—USCG and Washington DOE Data

Both the U.S. Coast Guard and Washington State Department of Ecology provided accident, incident and near loss data to the Puget Sound VTRA Accident-Incident database development effort. Both organizations capture data of interest to the database; however, there are several differences between the data provided by these key sources, as seen in Table A-6: these differences center on each organization's definition of a casualty; vessels of interest that are captured in the data records; the nature of in-transit failure data in the records; database and organizational changes that have impacted each organization's data collection and management activities; data used as input to each organization's records; and the nature of oil spill reporting in the data sources. Each of these items is discussed in the following section. The impact of these differences on the development of the Puget Sound VTRA Accident-Incident database is also discussed.

Table A-6 Differences Between Data Sources: USCG vs. Washington State DOE Records

Variable	USCG	DOE
Casualty	• No near miss events in the MISLE database. • Tracks personnel injury information • Tracks all marine event casualties	• No data on deaths, personnel injuries, or events that are not directly linked to spills. • Near miss data
Vessels of Interest	• Tracks all vessel types, including recreational vessels and personal watercraft, of any tonnage.	• Does not track events occurring on or to deck barges, fishing vessels, or vessels less than 300 GT.
In-transit failures	• Reports more small equipment failures leading to anchorage or Captain of the Port (COTP) actions.	• Captures equipment failures if they are reported as likely to precipitate a marine event or are involved in a marine event.
Database and Organizational Changes	• In December 2001, the Coast Guard migrated from the Marine Safety Information System (MSIS) to the Marine Information for Safety and Law Enforcement System (MISLE). MSIS had more detailed narrative reports than does MISLE.	• On July 1, 1997, the State's Office of Marine Safety (OMS) merged with DOE to form the new Spill Prevention, and Preparedness and Response Department (RCW 88.46.421). OMS was dissolved, and responsibility for vessel screening and spill reporting transferred to DOE.
Reporting sources	• Utilizes primary data sources: Coast Guard forms CG-2692 and CG-835, and other auxiliary reporting sources.	• Utilizes secondary data sources, frequently Coast Guard records.
Oil spills	• Uses National Response Center data to report incoming spill information for all kinds of vessels.	• No oil spill events occurring on or to deck barges, fishing vessels, or vessels less than 300 GT.

Definition of Casualty

The first differences between the Coast Guard and DOE casualty reporting systems with impact on the VTRA database were in each organization's definition of a casualty. The Coast Guard uses 46 CFR 4.05 to define a marine casualty as an "Intentional or Unintentional Grounding, Allision, Any loss of equipment that effects a loss of maneuverability, Any materiel deficiency or occurrence of materiality that affects seaworthiness or safety of the vessel (i.e. fire, flooding, loss of installed fire-fighting equipment), Death, Personnel Casualty that results in not fit for duty, Property damage of $25,000 or higher, an Oil Spill that creates a sheen or anything more, or a "Hazardous Condition".

In contrast, DOE uses WAC 317-31-030 and RCW 88.46.100 to define a marine "event" as a "Collision, Allision, Grounding, Near Miss Incident (through non-routine action avoided a collision, allision, grounding, or spill), or anything in CFR 46 4.05-1 EXCEPT Death, Personnel Injuries, and "Hazardous Conditions" not linked to a spill."

The primary difference between these two casualty definitions is that DOE does not collect data about deaths, personnel injuries, or events that are not directly linked to spills, following the organization's direction after the Washington Office of Marine Safety was abolished in 1997; examples of excluded events for DOE include personnel casualties not involved in oil spills, collisions, allisions, and groundings. On the other hand, the Coast Guard does not explicitly track near miss events in the MISLE database. Several reporting differences result: the DOE tracks near miss incidents, but the Coast Guard does not; the Coast Guard regularly tracks deaths, personnel casualties, and property damage events in excess of $25,000, while the DOE does not. However, inspection of the records shows that the Puget Sound VTS watchstanders may record some Near Miss Incidents for larger commercial traffic in their Near Miss or Watch Supervisor's Log. In terms of numbers of records, however, the most notable incongruence is that DOE does not track personnel casualties unrelated to oil spills, while the U.S. Coast Guard does.

Inspection of the data provides further insight. Between 1995 and 2005, 45 Near Miss incidents were reported; 12 were unique to the Coast Guard records, and 26 were unique to DOE records; 3 were reported by both the Coast Guard and DOE, and 4 were reported by other sources. These numbers support the observation that DOE reports contain more near miss events, but the scale is small enough that this explanation alone is insufficient. At the same time, between 1995 and 2005, there were a total of 175 personnel casualties reported, with 174 of those personnel casualties coming from USCG as the sole source. This illustrates that DOE does not track personnel casualties, but the USCG does.

Vessels of Interest to Organizations

Another difference in casualty reporting between USCG and Washington State DOE records lies in the nature of vessels and events of interest to each organization. USCG databases track all vessel types, including recreational vessels and personal watercraft, of any tonnage. However, the Spill Program of DOE uses a database called Marine Information System (MIS), specifically designed for vessels over 300 GT, excluding fishing boats and deck barges. As a result, DOE records do not include events occurring on or to deck barges, fishing vessels, or vessels less than 300 GT, both of which the Coast Guard tracks.

For the Puget Sound VTRA accident-incident database, events occurring to all vessels greater than 20 gross tons were captured; hence, both USCG and DOE data sources were important inputs to the database. Table A-7 shows the nature of the events that are tracked only by the USCG, primarily fishing vessels, public vessels, law enforcement events, deck barges, and vessels < 300GT. These events comprised 65% of the events in the VTRA accident-incident database, or 1759 records.

In-Transit Failures

In-transit failures are another source of data differences between the Coast Guard and DOE records. Coast Guard Seattle VTS captures Captain of the Port (COTP) actions and anchorages due to equipment failures through interaction with vessels and observing their actions at the VTS. DOE captures equipment failures if they are reported as likely to precipitate a marine event or if they are involved in a marine event. The result is that the Coast Guard reports more small equipment failures leading to anchorage or COTP actions, which are logged as part of the VTS watchstander's duties.

Table A-7 Puget Sound VTRA Accident Incident Database Events Tracked only by the USCG

Event Type	N	% of Events	Description
Fishing Accidents	444	25.24%	Fishing Vessel Accidents
Fishing Incidents	37	2.1%	Fishing Vessel Incidents
Other Accidents	174	9.89%	Public vessels
Other Accidents	181	10.29%	Non-Pollution Accidents (excludes Public)
Other Incidents	3	0.17%	Public vessels
Other Incidents	38	2.16%	Sector Seattle Anchor Log
Other Incidents	120	6.82%	Non-Pollution Incidents (excludes Public)
Tanker Incidents	36	2.05%	Sector Seattle Anchor Log
Tug Accidents	226	12.85%	Tugs under 300GT
Unusual Events	27	1.53%	Sector Seattle Anchor Log
Unusual Events	23	1.31%	USCG Law Enforcement (COTP holds, ROTR violations, etc.)
WSF Accidents	73	4.15%	WSF vessels under 300GT
WSF Incidents	377	21.4%	WSF vessels under 300GT
TOTAL	**1759**	**100%**	

Database and Organizational Changes

In addition to differences in reporting requirements, there are also differences in how each agency's reporting culture has evolved. Between 1995 and 2005, both agencies underwent a significant change in their reporting and database systems. In December 2001, the Coast Guard migrated from the Marine Safety Information System (MSIS) to the Marine Information for Safety and Law Enforcement System (MISLE). The transition caused a few months of data processing backlogs, but eventually all casualty records were transferred to the new database. However, the older Coast Guard database, MSIS, had more detailed narrative reports than does MISLE, making cross-referencing records and detailed casualty narratives after 2001 challenging, and changing the granularity of recent (post 2001) casualty information available through Coast Guard records.

Similarly, DOE underwent not only a database and reporting change, but also an organizational change. On July 1, 1997, the State's Office of Marine Safety (OMS) merged with DOE to form the new Spill Prevention, and Preparedness and Response Department (RCW 88.46.421). OMS was dissolved, and responsibility for vessel screening and spill reporting transferred to DOE. The DOE database, MIS, began as a vessel screening tool in OMS, and evolved to an event reporting database in DOE.

As a result of both organizational changes, data sources for the VTRA accident-incident database were of varying granularity and completeness, as each data collection organization evolved and changed its reporting processes and systems during the 1995-2005 time period. Impacts of these changes will be seen in the data analysis reported in Section A-5, particularly in the data available for human and organizational error (HOE) analysis. These are not uncommon challenges in large-scale systems with complex data, but the need to integrate multiple, independent sources into a coherent and common format, and the availability and granularity of data for HOE analysis, had impact on the VTRA accident-incident database development effort.

Primary and Secondary Reporting Sources

A large source of variation in event reporting in Puget Sound lies in the sources used as input by the two organizations. The Coast Guard reporting system uses primary sources as input, mainly the Coast Guard forms CG-2692 and CG-835. The Coast Guard thus develops an enormous repository of primary maritime accident and incident data; however, the varying databases which comprise this rich data resource are not electronically integrated into one common, accessible electronic format. This necessitates considerable knowledge of the existing databases, sources and repositories of information, as well as considerable time to gather, standardize, harmonize and integrate the disparate paper and electronic data sources. The unsuspecting analyst who is looking for a one-stop shopping experience with respect to U.S. maritime accident and incident data, therefore, is often disappointed and consequently forced to examine multiple data sources in order to attain a complete picture of maritime accidents and incidents in a system.

The Coast Guard utilizes several primary source reports. The CG-2692 form, the Report of Marine Accident, Injury, or Death, must be filled out for every reportable marine casualty as defined by the CFR. The CG-835 Form, the Notice of Merchant Marine Inspection Requirements, is completed when a vessel has materiel deficiencies that must be repaired before sailing. The Coast Guard also uses the Notice of Arrival Information managed by the Coast Guard's National Vessel Movement Center to track commercial vessel transits in major U.S. ports. The Coast Guard also has auxiliary reporting sources, including the VTS Watch Supervisor's Log, the Sector Seattle Anchor Database (also tracked by VTS when vessels arrange for anchoring), the VTS Intervention Log (when VTS must interact with vessels to prevent accidents), the VTS Near Miss Log (similar to the Intervention Log), as well as input from Coast Guard units such as Coast Guard Cutters, small boat stations, and the Sector Prevention and Response personnel.

The data from the Coast Guard data sources, however, is not captured or stored in one electronic integrated enterprise data warehouse, nor can data be easily shared or exchanged between Coast Guard databases. Thus, accident and incident analysts must identify all paper and electronic data sources available from the Coast Guard, in some cases through a Freedom of Information Act (FOIA) request; once identified, the records must be gathered from the archives, standardized, formatted, and integrated into a common electronic data format using a standard data classification scheme. As will be discussed in the next section, additional data were gathered from state, local, industry, non-profit and other sources. These data were also gathered, classified, standardized, integrated and validated with the Coast Guard data records. Thus, the effort to harmonize and integrate event data into a usable electronic format consumed significant effort and time.

The Washington DOE reporting system, in contrast, relies mostly on secondary data sources, frequently the Coast Guard, for its information. DOE uses a vessel screening tool that feeds information to its MIS database for the purpose of monitoring high-interest vessels (WAC 317-31-100). DOE also uses information from the Q-Line of the Coast Guard's Notice of Arrival Reports, and reports from actions taken by the Captain of the Port, Coast Guard Form CG-2692, and WSF Rider Alert Reports (which are not captured in the Coast Guard data). Prior to 2001, when the Office of Marine Safety existed, Washington DOE collected primary data in the form of boarding and risk evaluation reports. This primary data is contained in the pre-2001 DOE records, and in the VTRA accident-incident database for events that occurred prior to 2001.

Review of the DOE data shows that DOE has electronically captured records that specifically list the Coast Guard and WSF as sources in the written comments of the records; however, much of the Coast Guard data used in DOE data sources is not integrated into the primary Coast Guard marine casualty database, MISLE. Table A-8 lists the sources of the unique DOE records. Analysis of the DOE records shows that DOE databases contain records from the Coast Guard that the Coast Guard does not have available in the MSIS or MISLE databases. Integration of all available maritime safety data into a standard format electronic data warehouse would greatly enhance analysis, reporting and data maintenance activities.

Table A-8 Unique Data Sources in Washington DOE Records, 1995-2005, (Records Not Duplicated in Other Data Sources)

Source	# of Records	% of Records
CG Form CG-2692	89	32%
ANE Q-Line	17	6%
COTP Directives	36	13%
MSO Data Reports	36	13%
NRC Fax	1	0.1%
Pilot Reports	30	11%
VTS	11	4%
Unspecified USCG	5	2%
Shipping Company Reports	5	2%
WSF Rider Alert or Reports	47	17%
Total	**277**	

Oil Spill Reporting

A final source of difference between the Coast Guard and DOE records lies in the data sources used for oil spill data. The primary source of oil spill reporting for the Coast Guard is the Coast Guard's own National Response Center. The U.S. National Response Center is a Federally-funded, Federally-mandated "one-stop" reporting source for all the Coast Guard's incoming spill information, meeting the Federal requirements for spill reporting with one (800)-number phone call. VHF, UHF, and HF radio watchstanders also monitor communications for emergency response as well.

Washington State requires reporting to the State of Washington beyond the Federal standards (RCW 88.46.100). The U.S. National Response Center also sends the State of Washington a copy of reports of oil spills upon report of an accident in the state of Washington. Any differences in oil spill reporting between USCG and DOE are usually, but not always, related to the fishing, deck barge and 300 GT vessel record differences already discussed.

Impact of Data Sources on Puget Sound VTRA Accident-Incident Database

Examination of the differences between the data sources used to construct the Puget Sound VTRA Accident-Incident database underscores the importance of using multiple data sources when constructing databases that describe complex event sequences. However, the use of multiple data sources also requires extensive validation efforts and data checking. A common data dictionary was developed to standardize data entry and analysis, following the British Columbia/Pacific States Task Force oil spill reporting data dictionary, and validation activities comprised a significant work effort.

In contrast to other studies (Merrick, et al., 1992; Harrald, et al., 1998; Grabowski, et al., 2000; van Dorp, et al., 2001), there was considerably less proprietary data provided in the Puget Sound VTRA study. Perhaps this was the result of a study borne of litigation. However, perhaps because of the limited proprietary data sources, incident report rates are much lower (43%) in this study, compared to levels of 60-80% in other marine risk assessments. Accident rates appear higher, in contrast to incident rates, although the true reporting effect may be the lack of incident data. Computing mean time between failures (MTBF) and mean time to repair (MTTR) by vessel types was possible in earlier studies; this was not possible in this study because of the absence of sufficient, often proprietary, data. Each of these items impacted the data that was available for the accident-incident database analysis.

A-5. Database Analysis

Input to the accident-incident database was closed on June 1, 2007, in order to provide adequate time for analysis within the scope of the project. However, when new data sources were identified, they were incorporated into the database and the analysis, including U.S. Coast Guard 2692 and 835 accident reports provided by U.S. Coast Guard Headquarters. Descriptive statistics were developed using SAS version 9.0. Normalization was effected using transit data by vessel types for 1996-2005 provided by the U.S. Coast Guard Sector Seattle Vessel Traffic Service and the Puget Sound Marine Exchange. Transit data for the year 1995 was not available. Event frequencies were adjusted to the differing time periods captured in the database (1995-2005) and used for normalization (1996-2005). Although some of the data did not fail normality tests, both normal and non-parametric methods were used because of small sample sizes.

The Wilcoxon test, a non-parametric alternative to the paired Student's t-test for the case of two related samples or repeated measurements, is used to verify whether population means were equal. The test is used when the data are not normally distributed and when there are two levels for the factor. The Kruskal-Wallis test is also a non-parametric method used to verify whether the population means are equal when there are three or more levels for the factor. The test is also used when the normality test for the data fails. The Chi-square distribution assumption for the test statistic is valid when the sample size at each level is greater than or equal to 5. However, since the Kruskal-Wallis test was not able to give the direction of the test results, Tukey's HSD (Honestly Significant Differences) test was used to infer the difference of several means and also to construct simultaneous confidence intervals for these differences. The Tukey's HSD assumes that the displayed variables are independent and normally distributed with identical variance and it can rank means from different levels, which is important for the statistical analysis. The Kruskal-Wallis test was primarily used since it does not require the normality assumption. However, in this report, we found that both the Kruskal-Wallis and Tukey's HSC tests on Puget Sound VTRA data had similar results.

Maritime Events in Puget Sound, 1995-2005

The Puget Sound VTRA Accident-Incident database contains 2705 records of Puget Sound maritime events that occurred between 1995-2005, of which 54% (1462 events) were accidents, 43% (1159 events) were incidents, and 3.1% (84 events) were unusual events, as seen in Figure A-2. As described in the previous section, the proportion of accidents to incidents in the VTRA database is different from proportions observed in other risk assessment studies. For instance, in the 1988-1998 Washington State Ferries risk assessment, 25% of the 1229 events in the accident-incident database were accidents, and 75% of the events were incidents (Van Dorp, et al., 2001).

The proportional difference in the 1995-2005 VTRA database is attributed to a lack of available incident data, and the predominance of public, rather than proprietary, data in the database. In contrast, the 1988-1998 Washington State Ferries accident-incident database contained a great deal of proprietary machinery history data. No machinery history data and very little proprietary data were available for inclusion in the VTRA Accident-Incident database, which resulted in the accident-incident proportion illustrated in Figure A-2.

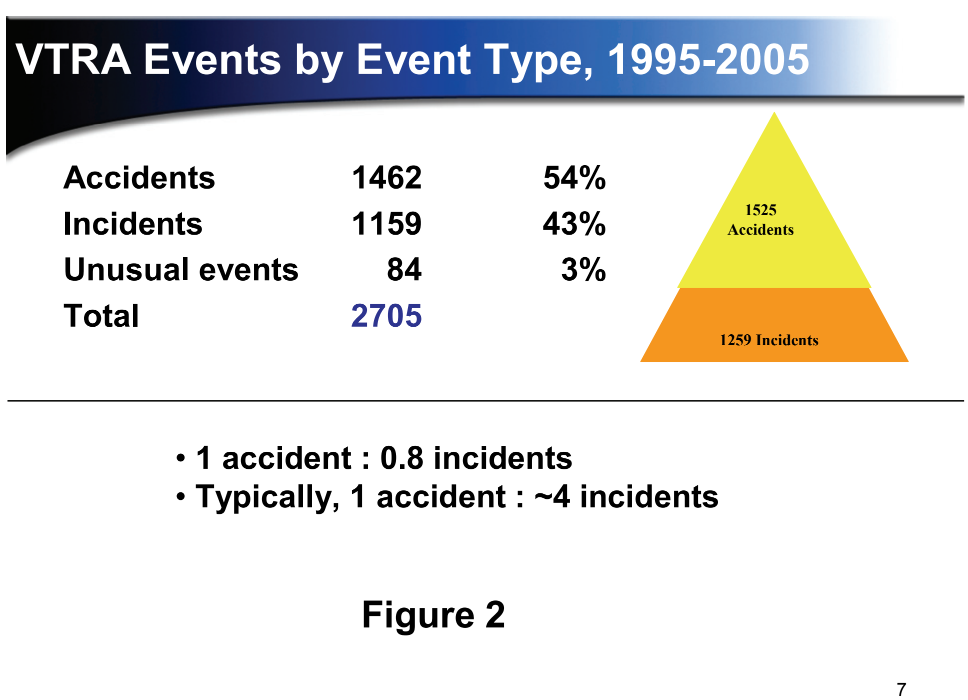

Figure A-3 shows these percentages in the form of an accident-incident pyramid, a representation commonly used to depict proportional relationships between accidents and incidents. Typically, the number and percentage of accidents in a safety-critical system is small, compared to the percentage of incidents; in marine transportation, a ratio of 1 accident for every 2-5 incidents is not unusual. Figure A-3 shows a greater percentage of accidents compared to incidents in the VTRA database; as just discussed, this may be related to the large number of accident records in the VTRA accident-incident database, and the absence of machinery history and proprietary incident data, as discussed previously.

An analysis of 1995-2005 accident-incident proportions by vessel type (Figure A-3) shows that ratios differ by vessel type: the ratio of accidents: incidents was greatest for fishing vessels, followed by tug-barges. These proportions were shown to be significantly different than the rest of the vessel types using the paired Wilcoxon Sign Rank Test at the 95% confidence interval (fishing>tug/barge>cargo>tanker=WSF).

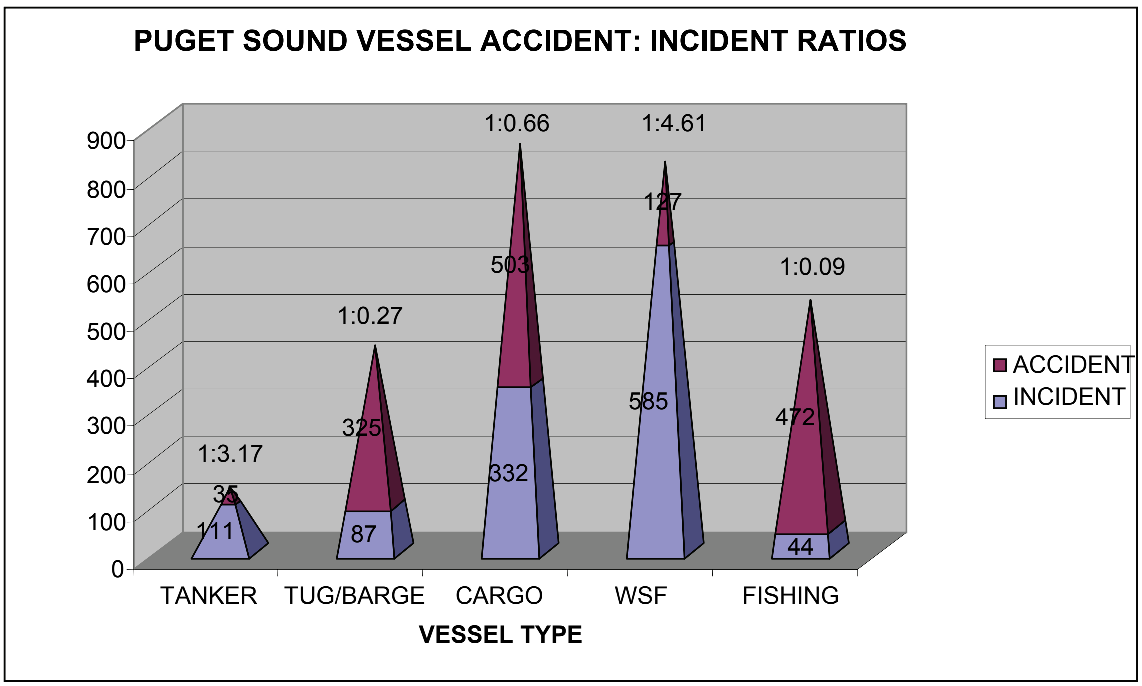

Figure A-3 Puget Sound Accident-Incident Ratios by Vessel Type, 1995-2005

Events by Year

Event frequencies varied over the time period, as seen in Figure A-4. Overall, the number of accidents and incidents has fallen dramatically since 2001; prior to 2001, the numbers of accidents and incidents were rising. As described earlier, up to and in 2001, several organizational changes occurred in the regulatory and reporting organizations, information technology and database changes occurred within those agencies, and heightened awareness and reporting was observed as a result of the events in the United States on September 11, 2001.

The event frequencies were first tested for normality. Since the normality test didn't fail, Tukey's HSD test was used, showing that years 1997-2002 had a significantly higher number of events than other years, and year 2005 had the lowest means of events. Anomalies with the accident and incident frequencies can also be noted in Figure A-4: in 1996, for instance, the number of incidents was greater than the number of accidents; similarly, in 2001, the number of accidents and incidents was identical. Analysis of the accidents shows that the year 2005 had the lowest frequency than other years in the 1995-2005 time frame; analysis of incidents using the same tests shows that the years 1996-2002 (with no differences among years 1996-2002) had significantly higher numbers of incidents than other years.

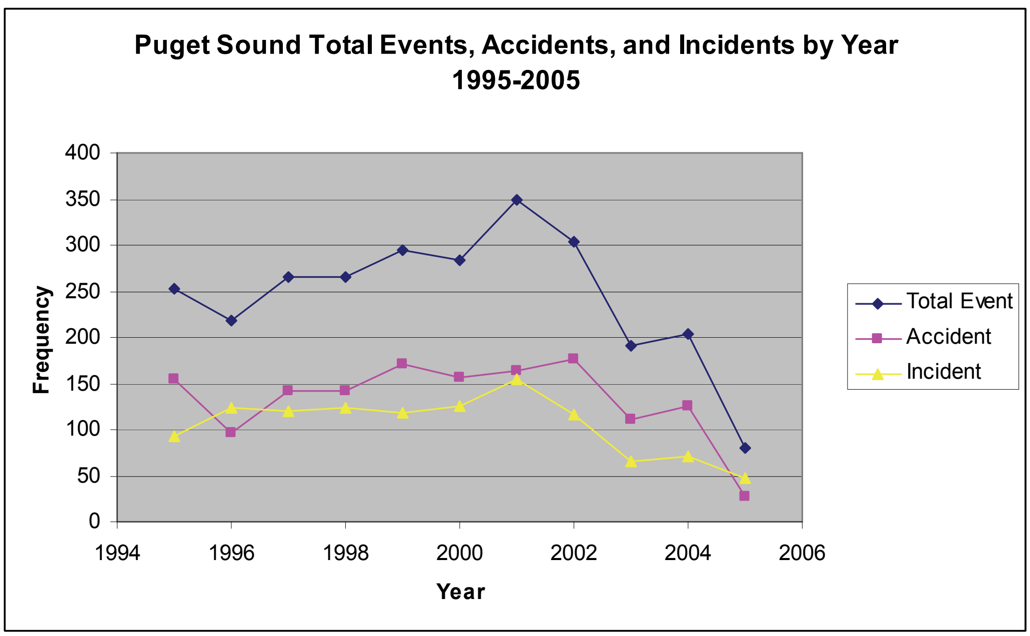

Figure A-4 Puget Sound Events and Event Types over Time, 1995-2005

Table A-9 shows the transit data from year 1996-2005 for each vessel type in Puget Sound. Note that transit data for 1995 was not available. Figure A-5 graphically illustrates the Table 9 data, and the predominance of Washington State Ferries transits, which comprised approximately 80% of all transits in Puget Sound between 1996 and 2005.

When the event data were normalized by the transit data, the results were slightly different from those obtained with the raw data, as shown in Table A-10. The normalized data test results show that years 1998-2002 had statistically higher event means than other years; for incidents, years 1996-2002 had significantly higher numbers of incidents than other years. Both raw data and normalization data test results are presented in the Table A-10.

Table A-9 Puget Sound Transit Data by Vessel Type, 1996-2005

	Tankers	%	Tug-Barge	%	Cargo	%	WSF	%	Other	%	Total
1996	2001	*1%*	24477	*10%*	12429	*5%*	196620	*81%*	7446	*3%*	**242973**
1997	2289	*1%*	30969	*13%*	16209	*7%*	176160	*76%*	7134	*3%*	**232761**
1998	2107	*1%*	25769	*11%*	13065	*6%*	180875	*80%*	3083	*1%*	**224899**
1999	2095	*1%*	27016	*12%*	9608	*4%*	194977	*83%*	801	*0%*	**234497**
2000	2557	*1%*	27553	*13%*	9551	*4%*	176567	*81%*	802	*0%*	**217030**
2001	2145	*1%*	24941	*11%*	9930	*5%*	179108	*82%*	1204	*1%*	**217328**
2002	1848	*1%*	24776	*11%*	9359	*4%*	176846	*79%*	12286	*5%*	**225115**
2003	1889	*1%*	26342	*12%*	9001	*4%*	176230	*77%*	14254	*6%*	**227716**
2004	2031	*1%*	24456	*12%*	8464	*4%*	167628	*82%*	1662	*1%*	**204241**
2005	2103	*1%*	24139	*12%*	8588	*4%*	166178	*82%*	1816	*1%*	**202824**
Total	**21065**	*1%*	**260438**	*12%*	**106204**	*5%*	**1791189**	*80%*	**50488**	*2%*	**2229384**

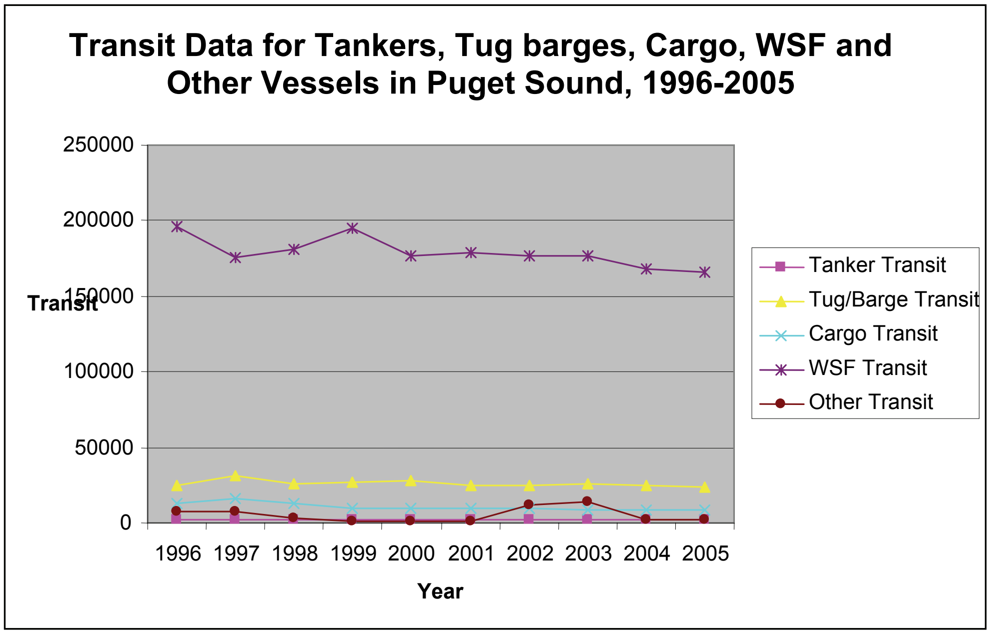

Figure A-5 Puget Sound Vessel Transits by Vessel Type, 1996-2005

Table A-10 Kruskal-Wallis and Tukey's HSD Tests Results of Raw and Normalized Total Events, Accidents and Incidents, 1995-2005

Variable		DF	Test Statistics	Test Result (Means with the same letter are not significantly different)
Raw Data (1995-2005)	Total Events	**10**	**Kruskal-Wallis: Chi-square statistic 60.1687, Pr > Chi-square <0.0001** **Tukey's HSD: F-value=11.27, Pr > F<0.0001**	**A:2001 2002 1999 2000 1997 1998 1995 B:2002 1999 2000 1997 1998 1995 1996 C: 1999 2000 1997 1998 1995 1996 2004 D: 2000 1997 1995 1996 2004 2003 E:2005** A>B>C>D>E
	Accidents	**10**	**Kruskal-Wallis: Chi-square statistic 51.6289, Pr > Chi-square <0.0001** **Tukey's HSD: F-value=8.88, Pr >F <0.0001**	**A:2002 1999 2001 2000 1995 1997 1998 2004 2003 B:2000 1995 1997 1998 2004 2003 1996 C: 2005** A>B>C
	Incidents	**10**	**Kruskal-Wallis: Chi-square statistic 56.7266, Pr> Chi-square < 0.0001,** **Tukey's HSD: F-value=8.61, Pr >F <0.0001**	**A:2001 2000 1998 1996 1997 1999 2002 B: 2000 1998 1996 1997 1999 2002 1995 C:1997 1999 2002 1995 2004 D: 1995 2004 2003 2005** A>B>C>D
Normalized Data (1996-2005)	Total Events	**9**	**Kruskal-Wallis: Chi-square statistic 59.0563, Pr > Chi-square <0.0001** **Tukey's HSD: F-value=13.40, Pr >F <0.0001**	**A:2001 2002 2000 1999 1998 B:2002 2000 1999 1998 1997 2004 C:2000 1999 1998 1997 2004 1996 D:1999 1998 1997 2004 1996 2003 E:2005** A>B>C>D>E
	Accidents	**9**	**Kruskal-Wallis: Chi-square statistic 51.1032, Pr > Chi-square =0.0017** **Tukey's HSD: F-value=9.94, Pr >F <0.0001**	**A:2002 2001 2000 1999 1998 2004 1997 B: 2001 2000 1999 1998 2004 1997 2003 C: 1998 2004 1997 2003 1996 D: 1996 2005** A>B>C>D
	Incidents	**9**	**Kruskal-Wallis: Chi-square statistic 51.1060, Pr> Chi-square < 0.0001** **Tukey's HSD: F-value=8.97, Pr >F <0.0001**	**A: 2001 2000 1998 2002 1997 1996 1999 B: 1998 2002 1997 1996 1999 2004 C: 1999 2004 C:1999 2004 2003 D: 2004 2003 2005** A>B>C>D

Bold results are statistically significant

Events by Vessel Type

Between 1995 and 2005, events in Puget Sound occurred to different vessels, as seen in Table A-11 and Figure A-6. The bulk of accidents between 1995 and 2005 occurred to cargo vessels (34%) and fishing vessels (32%). A paired Wilcoxon test shows that the proportion of accidents to total accidents occurring to cargo and fishing vessels was statistically higher over the time period than other vessels at the 95% confidence level. In contrast, most incidents between 1995 and 2005 occurred to Washington State Ferries (WSF) (50%) and cargo vessels (29%). A Wilcoxon test of proportions of the WSF incident frequencies shows the proportions to be statistically significant at the 95% confidence level, followed by cargo vessels. Finally, cargo vessels experienced the most (56%) of the 84 unusual events recorded in the database between 1995 and 2005. Thus, proportionally, cargo vessels experienced significantly more accidents, the 2nd-most level of incidents, and significantly more unusual events during the reporting period. Note that some of the data in Table A-11 are limited by small sample sizes.

Table A-11 Puget Sound Events by Vessel Type, 1995-2005

Event Type	Tankers	%	Tug-Barge	%	Cargo	%	WSF	%	Fishing	%	Total
Accidents	35*	*2%*	325	*22%*	**503**	*34%*	127	*9%*	**472**	*32%*	1462
Incidents	111	*10%*	87	*8%*	**332**	*29%*	**585**	*50%*	44	*4%*	1159
Unusual Events	25*	*30%*	9*	*11%*	**47**	*56%*	1*	*1%*	2*	*2%*	84
Total Events	171		421		882		713		518		2705

Bold results are statistically significant *** = small sample size**

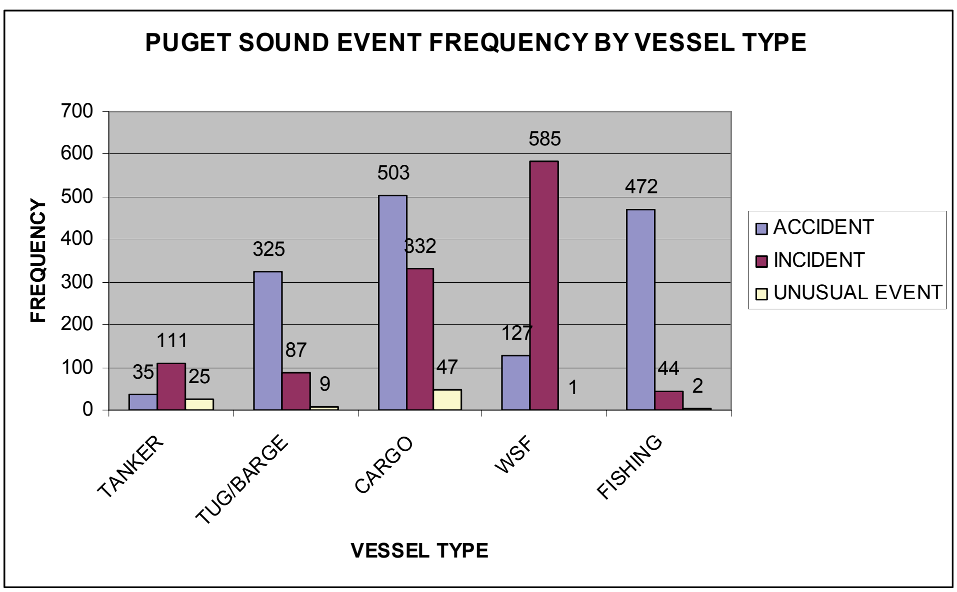

Figure A-6 Puget Sound Events by Vessel Type, 1995-2005

Normalizing the Table A-11 accident and incident data with the Table A-9 transit data provides normalized accident and incident rates by vessel types for the period 1996-2005, shown in Tables A-12 and A-13, which allows comparison of accident and incident rates for different vessel types using numbers of transits as a surrogate for exposure. Transit data for the year 1995 was not available from the U.S. Coast Guard.

Table A-12 Normalized Events by Transits, 1996-2005

	Tankers	Tug-Barge	Cargo	WSF	Fishing	Total
Accidents	0.001662*	0.001248	**0.004736**	7.09E-05	0.009349	0.000656
Incidents	**0.005269**	0.000334	**0.003126**	0.000327	0.000871	0.00052
Unusual Events	0.001187*	3.46E-05*	0.000443	5.58E-06*	3.96E-05*	3.77E-05
Total Events	**0.008118**	0.001617	**0.008305**	0.000398	0.01026	0.001213

*** = small sample size** **Bold results are statistically significant**

Results of the Kruskal-Wallis test showed that there were statistical differences for the normalized events, accidents, and incidents among the different vessel types. By using both Kruskal-Wallis and Tukey's HSD tests, cargo and tanker vessels were found to have significantly higher numbers of normalized events, compared to tug-barges and Washington State Ferries, over the period 1996-2005, as shown in Table A-13. Cargo vessels were shown to have significantly higher numbers of normalized accidents over the time period, compared to the other vessel types. Tanker vessels were shown to have significantly higher numbers of normalized incidents over the time period, compared to the other vessel types. The normalized results are statistically different from the raw data results, as raw tanker incidents and total events were not statistically significant, while the normalized incidents for tankers are.

Table A-13 Kruskal-Wallis and Tukey's HSD Test Result, Raw and Normalized Events Types by Vessel Types, 1995-2005

Variable		DF	Test Statistics	Direction
Raw Data 1995-2005	Total Event	4	Kruskal-Wallis: Chi-square statistic 34.2814, Pr > Chi-square <0.0001 Tukey's HSD: F value= 19.24, Pr>F <0.0001	**A: Cargo = WSF** **B: WSF Fishing** **C: Fishing Tug/barge** **D: Tanker** **A>B>C>D**
	Accident	4	Kruskal-Wallis: Chi-square statistic 39.0843, Pr > Chi-square <0.0001 Tukey's HSD: F Value =26.82, Pr>F <0.0001	**A: Cargo Fishing** **B: Fishing Tug/barge** **C: WSF Tanker*** **A>B>C**
	Incident	4	Kruskal-Wallis: Chi-square statistic 40.7493, Pr > Chi-square <0.0001 Tukey's HSD: F Value= 39.92, Pr>F <0.0001	**WSF> Cargo> Tanker= Tug/barge = Fishing**
Normalized Data 1996-2005	Total Event	3	Kruskal-Wallis: Chi-square statistic 32.9020, Pr > Chi-square <0.0001 Tukey's HSD: F value= 19.17, Pr>F <0.0001	**Cargo=Tanker>Tug/barge=WSF**
	Accident	3	Kruskal-Wallis: Chi-square statistic 27.3205, Pr > Chi-square <0.0001 Tukey's HSD: F Value =26.53, Pr>F <0.0001	**A: Cargo** **B: Tanker* Tug/barge** **C: Tug/barge WSF** **A>B>C**
	Incident	3	Kruskal-Wallis: Chi-square statistic 24.1537, Pr > Chi-square <0.0001 Tukey's HSD: F Value= 20.99, Pr>F <0.0001	**Tanker>Cargo>Tug/barge=WSF**

Bold results are statistically significant *** = small sample size**

Additional analysis was undertaken to determine whether there were statistically significant differences between raw and normalized accident and incident frequencies for all vessel types (Table A-14). Comparing the raw and normalized accident:incident frequencies using a Wilcoxon test shows that for both raw and normalized events, tankers and WSF had significantly higher incident frequencies than accident frequencies; and tug-barges and cargo ships had significantly higher accident frequencies than incident frequencies (Table A-14). Note that the results for tanker accidents were limited by small sample sizes.

Table A-14 Wilcoxon Test and P-value of Normalized and Raw Accidents and Incidents, 1995-2005, Tankers, Tug-Barges, Cargo Ships, WSF, and Fishing Vessels

Variable		N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Raw Data (1995-2005)	**Tanker**	**11**	81.5000	-2.9760	**0.0029**	**Incident>Accident***
	Tug/barge	**11**	178.5000	3.4184	**0.0006**	**Accident>Incident**
	Cargo	**11**	166.0000	2.5938	**0.0095**	**Accident>Incident**
	WSF	**11**	70.5000	-3.6856	**0.0014**	**Incident>Accident**
	Fishing	**11**	184.5000	3.8237	**0.0001**	**Accident>Incident**
Normalized Data (1996-2005)	**Tanker**	**10**	70.5000	-2.6089	**0.0173**	**Incident>Accident***
	Tug/barge	**10**	148.0000	3.2505	**0.0012**	**Accident>Incident**
	Cargo	**10**	132.0000	2.0410	**0.0413**	**Accident>Incident**
	WSF	**10**	59.0000	-3.4773	**0.0005**	**Incident>Accident**

* = small sample size **Bold results are statistically significant**

Events by Location

Events in Puget Sound occurred in different geographical areas, as can be seen in Table A-15 and Figure A-7. South Puget Sound had the most events from 1995 to 2005. Kruskal-Wallis and Tukey's HSD tests were used to analyze the differences between the frequency of events, accidents, and incidents in the different zones; the number of events occurring in South Puget Sound was significantly higher than those occurring in other areas at the 95% confidence level (Table A-16). Events by location were not able to be normalized by transits because transit data by location was not available. Note that the data in Tables A-15 and A-16 are limited by small sample sizes.

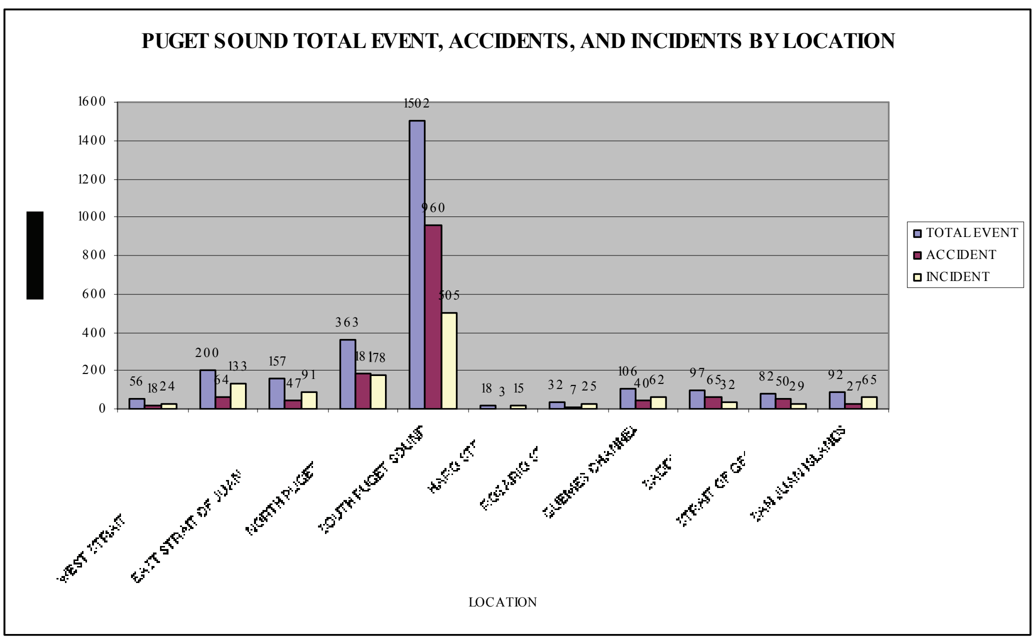

Figure A-7 Puget Sound Event Types by Location, 1995-2005

Table A-15 Puget Sound Events, Accidents, Incidents and Unusual Events by Location, 1995 – 2005

Zone	Total Events		Accident		Incident		Unusual Event	
	N	%	N	%	N	%	N	%
West Strait of Juan de Fuca	200	7.4%	64	4.4%	133	11.5%	3*	3.6%
East Strait of Juan de Fuca	157	5.8%	47	3.2%	91	7.9%	19*	22.6%
North Puget Sound	363	13.4%	181	12.4%	178	15.4%	4*	4.8%
South Puget Sound	**1502**	**55.5%**	**960**	**65.7%**	**505**	**43.6%**	**37**	**44.0%**
Haro Strait / /Boundary Pass	18*	0.7%	3*	0.2%	15*	1.3%	0	0.0%
Rosario Strait	32*	1.2%	7*	0.5%	25*	2.2%	0	0.0%
Guemes Channel	106	3.9%	40	2.7%	62	5.3%	4*	4.8%
Saddlebag	97	3.6%	65	4.4%	32*	2.8%	0	0.0%
Strait of Georgia /Cherry Point	82	3.0%	50	3.4%	29*	2.5%	3*	3.6%
San Juan Islands	92	3.4%	27*	1.8%	65	5.6%	0*	0%
Unknown	56	2.1%	18*	1.2%	24*	2.1%	14*	16.7%
Total	**2705**		**1462**		**1159**		**84**	

*** = small sample size** **Bold results are statistically significant**

Table A-16 Kruskal-Wallis and Tukey's HSD Test Results for Raw Events by Locations, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	9	Kruskal-Wallis: Chi-square statistic 80.7694, Pr>Chi-square<0.0001 Tukey's HSD: F-value= 81.20, Pr >F <0.0001	**Location South Puget Sound had higher number of events than other locations***
Accidents	9	Kruskal-Wallis: Chi-square statistic 79.5272, Pr > Chi-square <0.0001 Tukey's HSD: F-value =79.24, Pr >F <0.0001	**Location South Puget Sound had higher number of accident frequency than other locations***
Incidents	9	Kruskal-Wallis: Chi-square statistic 79.2347, Pr > Chi-square <0.0001 Tukey's HSD: F-value= 44.79, Pr >F <0.0001	**Location South Puget Sound had higher number of incident frequency than other locations***

*** = small sample size** **Bold results are statistically significant**

Events by Season

Events in Puget Sound between 1995-2005 varied by season, as seen in Tables A-17 and A-18. Per input from Puget Sound experts, summer was defined as the months from May to September; winter was defined as the months from November to March. As can be seen in Table A-17, most of the events between 1995 and 2005 occurred in the summer and winter seasons (39.9% and 37.7%, respectively). Accidents occurred most often in the summer (42.4%) and in the winter (39.1%). Incidents occurred most often in the summer (36.5%) and winter (35.5%) as well. For raw numbers of events, a Tukey's HSD test showed that summer and winter had significantly higher number of events, accidents, and incidents than autumn and spring did, and summer was the most significant event period for all event types (Table A-19).

However, when the data were normalized by transits, spring and autumn had a significantly higher number of normalized total events and incidents, compared to winter and summer, and no differences for the normalized accidents were noted among the four seasons. This is another example of the importance of normalizing results by transits. The differing results for the normalized data may be because for the raw data, summer and winter have many more events than spring and autumn since summer was assumed from May to September and winter from November to March, while spring and autumn had just one month, April and October separately. For the normalized data, the transits are higher because there are five months in those seasons. Therefore, there is no statistically significant difference for normalized total events and accidents.

Table A-17 Puget Sound Events by Season, 1995-2005

Year	Total			Spring			Summer			Autumn			Winter		
	Event	Accident	Incident	Event	Accident	Incident	Event	Accident	Incident	Event	Accident	Incident	Event	Accident	Incident
1995	253	154	93	26*	12*	14*	94	64	28*	26*	11*	15*	107	67	36*
1996	219	96	123	26*	6*	20*	91	46	45	44	17*	27*	58	27*	31*
1997	265	142	120	33*	14*	19*	86	51	35*	40	19*	21*	106	58	45
1998	265	141	124	42	10*	32*	91	54	37*	34*	15*	19*	98	62	36*
1999	294	171	118	30*	16*	14*	130	81	48	40	18*	22*	94	56	34*
2000	283	156	126	31*	9*	22*	120	67	52	27*	12*	15*	105	68	37*
2001	349	164	154	35*	14*	21*	151	76	60	40	14*	20*	123	60	53
2002	303	176	117	34*	21*	13*	126	79	44	20*	10*	7*	123	66	53
2003	191	110	66	15*	13*	2*	69	38*	23*	16*	9*	7*	91	50	34*
2004	203	125	71	21*	11*	10*	85	53	29*	17*	13*	1*	80	48	31*
2005	80	27	47	6*	4*	2*	36*	11*	22*	4*	2*	2*	34*	10*	21*
Total	**2705**	**1462**	**1159**	**299**	**130**	**169**	**1079**	**620**	**423**	**308**	**140**	**156**	**1019**	**572**	**411**

*** = small sample size**

Table A-18 Puget Sound Normalized Events by Season (Normalized by Transits), 1996-2005

Year	Spring	Normalized data			Summer	Normalized data			Autumn	Normalized data			Winter	Normalized data		
	Transits	Event	Accident	Incident	Transits	Event	Accident	Incident	Transits	Event	Accident	Incident	Transits	Event	Accident	Incident
1996	21776	0.0012	0.0006	0.0006	107320	0.0009	0.0006	0.0003	17944	0.0014	0.0006	0.0008	95933	0.0011	0.0007	0.0004
1997	17839	0.0015	0.0003	0.0011	92696	0.0010	0.0005	0.0005	21457	0.0021	0.0008	0.0013	100769	0.0006	0.0003	0.0003
1998	17395	0.0019	0.0008	0.0011	96358	0.0009	0.0005	0.0004	17639	**0.0023**	0.0011	0.0012	93507	0.0011	0.0006	0.0005
1999	17556	0.0024	0.0006	0.0018	104966	0.0009	0.0005	0.0004	19686	**0.0017**	0.0008	0.0010	92289	0.0011	0.0007	0.0004
2000	18589	0.0016	0.0009	0.0008	95194	0.0014	0.0009	0.0005	17090	0.0023	0.0011	0.0013	86157	0.0011	0.0007	0.0004
2001	17738	**0.0017**	0.0005	0.0012	95379	0.0013	0.0007	0.0005	20066	**0.0013**	0.0006	0.0007	84145	0.0012	0.0008	0.0004
2002	18319	**0.0019**	0.0008	0.0011	95534	0.0016	0.0008	0.0006	18303	0.0022	0.0008	0.0011	92959	0.0013	0.0006	0.0006
2003	19458	0.0017	0.0011	0.0007	97023	0.0013	0.0008	0.0005	18303	0.0011	0.0005	0.0004	92932	0.0013	0.0007	0.0006
2004	16346	0.0009	0.0008	0.0001	87806	0.0008	0.0004	0.0003	17458	0.0009	0.0005	0.0004	82631	0.0011	0.0006	0.0004
2005	16409	0.0013	0.0007	0.0006	87421	0.0010	0.0003	0.0003	16839	0.0010	0.0008	0.0001	82155	0.0010	0.0006	0.0004

Bold results are statistically significant

Table A-19 Kruskal-Wallis and Tukey's HSD tests of Raw and Normalized Events, Accidents, and Incidents by Season, 1996-2005

Variable		DF	Test statistic	Direction
Raw	Total Events	3	Kruskal-Wallis: Chi-square statistic 29.3489, Pr>Chi-square <0.0001 Tukey's HSD: F-value=56.31, Pr >F <0.0001	**Summer=Winter>Autumn =Spring***
	Accidents	3	Kruskal-Wallis: Chi-square statistic 29.4899, P>Chi-square <0.0001 Tukey's HSD: F-value=69.62, Pr >F <0.0001	**Summer=Winter > Autumn = Spring***
	Incidents	3	Kruskal-Wallis: Chi-square statistic 27.5853, P>Chi-square < 0.0001 Tukey's HSD: F-value=21.83, Pr >F <0.0001	**Summer=Winter > Spring= Autumn***
Normalized	Total Events	3	Kruskal-Wallis: Chi-square statistic 13.2963, P>Chi-square =0.0040 Tukey's HSD: F-value=6.71, Pr >F =0.0012	**Autumn=Spring> Winter =Summer***
	Accidents	3	Kruskal-Wallis: Chi-square statistic 1.0841, P>Chi-square =0.7809 Tukey's HSD: F-value=0.78, Pr >F =0.5154	**N/A**
	Incidents	3	Kruskal-Wallis: Chi-square statistic 14.9298, P>Chi-square =0.0019 Tukey's HSD: F-value=8.07, Pr >F =0.0004	**Spring=Autumn> Winter =Summer***

*** = small sample size** **Bold results are statistically significant**

When a seasonality index was constructed to assess the likelihood of events, accidents, and incidents in Puget Sound by season between 1995 and 2005, this analysis (Table A-20) showed that events occurred more often in summer and winter than in the spring and autumn, due to the longer periods; for normalized events, spring and autumn had slightly more events than summer and winter. Note again that these data are also limited by small sample sizes.

Table A-20 Raw and Normalized Seasonal Index for Total Events, Accidents, and Incidents, 1996-2005

Season	Raw Seasonal Index		
	Total Events	Accidents	Incidents
Spring	0.444	0.350	0.590
Summer	1.585	1.679	1.460
Autumn	0.450	0.375	0.555
Winter	1.536	1.591	1.408
	Normalized Seasonal Index		
Spring	1.190477	1.048649	1.399870
Summer	0.801881	0.931193	0.666871
Autumn	1.194303	1.091444	1.260790
Winter	0.813435	0.9281	0.67253

Events by Time of Day

Events that occurred in the Puget Sound VTRA area between 1995 and 2005 were characterized as occurring during the day or night. Per input from Puget Sound maritime experts, day was defined from 6am to 8pm in the spring and summer and 7am to 7pm in the autumn and winter. The data collected are shown in the Table A-21.

Table A-21 Total Events, Accidents, and Incidents by Day and Night
N: Number of Frequency; %: Percent of Frequency, 1995-2005

Time of Day	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
Day	1317	48.7	771	52.7	526	45.4
Night	510	18.9	208	14.2	293	25.3
Null	878	32.4	483	33.0	340	29.3
Total	**2705**	**100**	**1462**	**100**	**1159**	**100**

From Table A-21, it can be seen most total events, accidents, and incidents occurred during the day. One of the obvious reasons is that there are more transits, particularly for WSF vessels, which comprise 80% of all transits, during the day than at night. A Wilcoxon test (Table A-22) on the raw data showed no statistical differences between total events and accident frequencies between day and night. However, vessels had a statistically higher number of incidents during the day than the night. Caution is noted with the results in Table A-22, however, because of the high proportion of null values for day and night. In addition, normalization by transit data was not available by time of day.

Table A-22 Wilcoxon Test on the Total Events, Accidents, and Incidents Frequencies by Time of Day, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	**11**	153.5000	1.7735	0.0762	N/A
Accidents	**11**	152.5000	1.7087	0.0875	N/A
Incidents	**11**	156.5000	1.9739	**0.0484**	**Day>Night**

Bold results are statistically significant

Events by Vessel Flag

Events of interest that occurred in the Puget Sound VTRA area between 1995 and 2005 occurred aboard vessels of varying flags, as seen in Figure A-8 and in Table A-24. More events occurred to U.S. flag vessels during the reporting period than to non-U.S. flag vessels; these differences were significant at the 95% confidence level using the Wilcoxon test (Table A-23).

Similarly, significantly more accidents (1028, 70.3%) occurred to U.S. flag vessels than to non-U.S. flag vessels; these differences were found to be significant at the 95% level, using the Wilcoxon test. A similar pattern was observed in total numbers of incidents over the time period, with 72.9% of the incidents occurring to U.S.-flag vessels. These differences were found to be significant at the 95% level using the Wilcoxon test. Unfortunately, transit data was not available by vessel flags to compare normalized results.

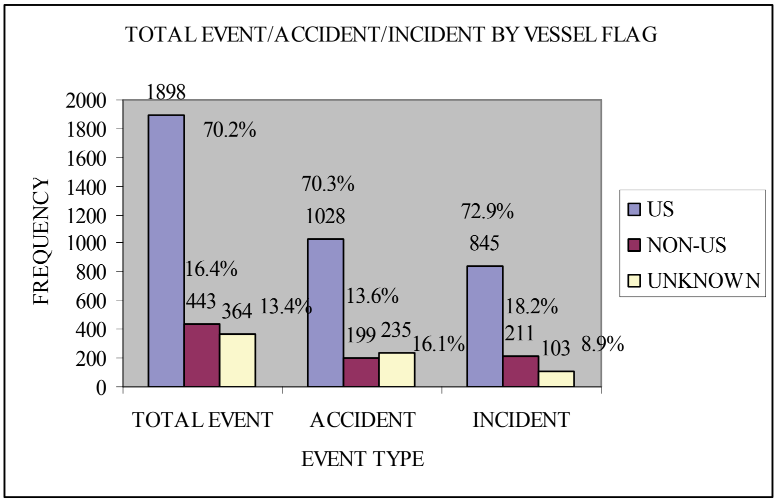

Figure A-8 Puget Sound Accident and Incident Frequencies by Vessel Flag, 1995-2005

Table A-23 Wilcoxon Test on Total Events, Accidents, Incidents by Vessel Flag, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	**11**	184.0000	3.7768	**0.0002**	**U.S.>Non U.S.**
Accidents	**11**	179.5000	3.4871	**0.0005**	**U.S.>Non U.S.**
Incidents	**11**	187.0000	3.9795	**<0.0001**	**U.S.>Non U.S.**

Bold results are statistically significant

Events occurred to vessels of various flags, as seen in Table A-24.

Table A-24 Puget Sound Total Events, Accidents and Incidents by Vessel Flag, 1995-2005

Vessel Flag	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
U.S.	1898	70.2	1028	70.3	845	72.9
Bahamas	34*	1.25	11*	0.75	23*	1.98
Canada	34*	1.25	28*	1.92	6*	0.52
Cyprus	21*	0.78	10*	0.68	11*	0.95
Liberia	40	1.48	15*	1.03	20*	1.72
Panama	84	3.10	30*	2.05	45	3.88
Russia	37*	1.37	31*	2.12	6*	0.52
Singapore	25*	0.9	5*	0.34	18*	1.55
Other	168	6.2	69	4.72	82	7.1
Unknown	364	13.4	235	16.1	103	8.9
Total	**2705**	**100**	**1462**	**100**	**1159**	**100**

*** = small sample size**

A subset of Table A-24, events that occurred to non-U.S. flag vessels between 1995 and 2005, is shown in Table A-25.

Table A-25 Puget Sound Non U.S. Flag Events, 1995-2005

Vessel Flag	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
Bahamas	34*	7.7	11*	5.5	23*	10.9
Canada	34*	7.7	**28***	**14.1**	6*	2.8
Cyprus	21*	4.7	10*	5	11*	5.2
Liberia	40	9.0	15*	7.5	20*	9.5
Panama	**84**	**19.0**	**30***	**15.1**	**45**	**21.3**
Russia	37*	8.4	**31***	**15.3**	6*	2.8
Singapore	25*	5.6	5*	2.5	18*	8.5
Other	168	37.9	69	34.7	82	38.9
Total	443	100	199	100	211	100

*** = small sample size** **Bold results are statistically significant**

Table A-25 shows that, of the non-U.S. flag events that occurred between 1995 and 2005, 19% of events, 15.1% of accidents, and 21.3% of incidents occurred to Panamanian flag vessels. A group of 'other' non U.S. flag vessels—other than Bahamian, Canadian, Cypriot, Liberian, Panamanian, Russian and Singapore—comprised the largest group of non U.S.-flag events (37.9% of events, 34.7% of accidents, and 38.9% of incidents). Using the Kruskal-Wallis and Tukey's HSD tests upon raw data, the results show that Panamanian flag vessels had significantly higher total events and incident frequencies then vessels from other flags. In addition, Canadian, Panamanian and Russian flag vessels had significantly higher accident frequencies than vessels from other flags (Table A-26). Note that these data are limited by small sample sizes, and transit data by flag was not available to normalize the data.

Table A-26 Kruskal-Wallis and Tukey's HSD tests of Raw Events, Accidents, and Incidents Frequencies by Foreign Vessel Flag, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	6	Kruskal-Wallis: Chi-square statistic 21.0342, P>Chi-square =0.0026 Tukey's HSD: F-value= 32.65, Pr >F <0.0001	**Panama> Bahamas= Canada =Cyprus =Liberia = Russia =Singapore**
Accidents	6	Kruskal-Wallis: Chi-square statistic 21.5897, P>Chi-square =0.0014	**Panama= Canada= Russia> Bahamas =Cyprus =Singapore**
Incidents	6	Kruskal-Wallis: Chi-square statistic 23.0145, P>Chi-square =0.0011 Tukey's HSD: F-value =17.20, Pr >F <0.0001	**Panama> Bahamas= Canada =Cyprus =Liberia = Russia =Singapore**

*** = small sample size**

Events by Owner

An analysis of events by vessel owner is presented in Table A-27. Note that vessel owner data is dynamic, as some vessel owners may no longer exist, or some vessels may have changed their operators during the period for which the database captures information. Table A-27 presents event information for owners that have more than 30 events between 1995 and 2005, excluding the Washington State Ferries.

Table A-27 Puget Sound Events by Vessel Owners, 1995-2005

OWNER	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
Foss	68	100	54	79.4	10*	14.7
U.S. Navy	56	100	44	78.6	9*	16.1
Crowley	56	100	46	82.1	10*	17.9
U.S. Coast Guard	44	100	44	100	0	0
Clipper Navigation, Inc.	36*	100	12*	33.3	22*	61.1
Olympic Tug and Barge, Inc.	30*	100	23*	76.7	7*	23.3

N: Number of total events, accidents, incidents; %: Percent of accidents or incidents of total events

*** = small sample size**

In Table A-27, it can be seen that most of the vessel owners in the table have higher accident frequencies than incident frequencies, except Clipper Navigation, Inc. There are differences between different owners with respect to accident and incident frequencies, as seen in Table A-28; however, a Kruskal-Wallis and Tukey's HSD analysis on the raw data show no significant differences for total events among the vessel owners. Transit data by owner was not available to normalize this data.

Table A-28 Kruskal-Wallis and Tukey's HSD tests of Raw Events, Accidents, and Incidents by Vessel Owner, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	5	Kruskal-Wallis: Chi-square statistic 8.3655, P>Chi-square =0.1390	N/A
Accidents	5	Kruskal-Wallis: Chi-square statistic 20.9822, P>Chi-square =0.0010 Tukey's HSD: F-value=4.60, Pr >F=0.0016	**A: Foss Crowley US Navy USCG Olympic Tug and Barge B: Olympic Tug and Barge, Clipper A>B ***
Incidents	5	Kruskal-Wallis: Chi-square statistic 11.6234, P>Chi-square =0.0440 Tukey's HSD: F value 2.56, Pr>F 0.0445	**A: Clipper, Crowley, Foss, US Navy, Olympic Tug and Barge B: Crowley, Foss, US Navy, Olympic Tug and Barge, USCG A>B ***

*** = small sample size** **Bold results are statistically significant**

Events by Classification Society

Class society information for the VTRA accident-incident records were obtained from Lloyd's List. Although the classification society for vessels can vary over time, the classification society for the vessel at the time of the recorded event was captured in the database. The major classification societies include the American Bureau of Shipping (ABS), Det Norske Veritas Classification A/S (DNV), Nippon Kaiji Kyokai (NK), and Lloyd's Register (LR). Total events, accidents, incidents, and unusual events by vessel registered with various class societies are found in the Table A-29. Note that much of the data in Table A-29 and the results in Table A-30 are limited by small sample sizes.

Table A-29 Puget Sound Event Types by Classification Society, 1995-2005

Class Society	Total Events	Accidents	Incidents	Unusual Events
ABS	318	166	131	21*
Bureau Veritas (BV)	20*	12*	5*	3*
China Classification Society (CS)	8*	1*	3*	4*
China Corp. Register of Shipping (CR)	2*	0	1*	1*
Croatian Register of Shipping (HV)	1*	0	1*	0
Germanischer Lloyd (GL)	24*	7*	12*	5*
Korean Register of Shipping (KR)	12*	4*	4*	4*
Lloyd's Register (LR)	27*	15*	10*	2*
Nippon Kaiji Kyokai (NK)	70	19*	36*	15*
Det Norske Veritas Classification A/S (DNV)	83	36*	40	7*
Registro Italiano Navale (RINA)(RI)	5*	2*	2*	1*
Russian Maritime Register of Shipping (RS)	20*	14*	6*	1*
Null	2115	1186	908	20
Total	**2705**	**1462**	**1159**	**84**

*** = small sample size**

Kruskal-Wallis and Tukey's HSD tests on the class society data showed that ABS class vessels had a statistically higher number of total events, accidents, and incidents than those belonging to other classification societies (Table A-30). Normalization data by vessel class was not available for this analysis.

Table A-30 Kruskal-Wallis and Tukey's HSD tests of Raw Events, Accidents and Incidents by Class Society

Variable	DF	Test Statistics	Direction
Total Events	3	Kruskal-Wallis: Chi-square statistic 30.4518, P>Chi-square <0.0001 Tukey's HSD: F-value=34.16, Pr >F <0.0001	**ABS>DNV=NK=LR***
Accidents	3	Kruskal-Wallis: Chi-square statistic 26.6617, P>Chi-square <0.0001 Tukey's HSD: F-value= 54.05, Pr >F <0.0001	**ABS>DNV*=NK*=LR***
Incidents	3	Kruskal-Wallis: Chi-square statistic 28.0562, P>Chi-square <0.0001 Tukey's HSD: F-value= 20.21, Pr >F <0.0001	**ABS>DNV*=NK*=LR***

*** = small sample size** **Bold results are statistically significant**

Events by Weather Conditions

Weather condition information for every record in the VTRA database was not available.

Events by Direction (Inbound/Outbound)

Information about the direction in which the vessel was traveling was available for some events from CG 2692 and 835 reports. Note that of the 2705 events in the database, directional information was only available for 110 of those events. Of the 110, 92 events occurred to inbound vessels and 18 events occurred to outbound vessels. The accident, incident and unusual event records are shown in Table A-32. Note that the data in Tables A-31 and A-32 are limited by small sample sizes.

Table A-31 Puget Sound Events by Direction, 1995-2005

DIRECTION	Total Events		Accidents		Incidents		Unusual Events	
	N	%	N	%	N	%	N	%
Inbound	92	100	5*	5.4	86	93.5	1*	1.1
Outbound	18*	100	0*	0	14*	77.8	4*	22.2
Total	**110**	**100**	**5***	**4.5**	**100**	**90.9**	**5***	**4.5**

*** = small sample size**

In Table A-31, both inbound and outbound vessels have many more incidents than accidents. A Wilcoxon test on the data in Table A-32 shows that inbound vessels had significantly higher numbers of total event and incident frequencies than did outbound vessels. No significant differences were found for accident frequencies for inbound vessels and outbound vessels. Note that the small percentage of records with directionality information suggest that these results may or may not be representative of data for the entire VTRA area.

Table A-32 Wilcoxon tests on total event/accident/incident frequency by Direction

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	**11**	172.500	3.0474	**0.0023**	**Inbound>Outbound***
Accidents	**11**	143.000	1.8166	0.0693	N/A
Incidents	**11**	170.500	2.9421	**0.0033**	**Inbound>Outbound ***

*** = small sample size** **Bold results are statistically significant**

Events by Accident/Incident Type

Ten types of accidents were captured in the Puget Sound VTRA accident-incident database: pollution, allisions, breakaways, capsizings, collisions, fire and/or explosions, flooding, groundings, salvage, and sinkings (Table A-33). Six types of incidents were also captured:

equipment failures, loss of power, loss of propulsion, loss of steering, near misses, and structural failure and/or damage (Table A-34). Note that much of the data, and the results in Table A-35, are limited by small sample sizes.

Table A-33 Puget Sound Accident Frequency by Accident Type, 1995-2005

Accident Type	**Allision**	**Breakaway**	**Capsize**	**Collision**	**Fire/explosion**
Frequency	204	8 *	12 *	50	55
Accident Type	**Flooding**	**Grounding**	**Pollution**	**Salvage**	**Sinking**
Frequency	25 *	65	1005	0 *	38 *

***= small sample size**

Table A-34 Puget Sound Incident Frequency by Incident Type, 1995-2005

Incident Type	**Equipment Failure**	**Loss of power**	**Loss of propulsion**	**Loss of steering**	**Near miss**	**Structural failure/damage**	**Loss of anchor**
Frequency	744	30 *	227	67	40	42	9*

- **= small sample size**

Tables A-33 and A-34 show that the predominant accident type is pollution, and the leading incident type is equipment failure. Kruskal-Wallis and Tukey's HSD tests also showed that there were statistical differences among accident and incident types (Table A-35), although the results were limited by small sample sizes.

Table A-35 Kruskal-Wallis and Tukey's HSD test results on Accident and Incident types, 1995-2005

Variable	**DF**	**Test Statistics**	**Direction**
Accident Type	**9**	Kruskal-Wallis: Chi-square statistic 69.4233, P>Chi-square <0.0001 Tukey's HSD: F-value= 78.22, Pr >F <0.0001	**A:Pollution B:Allision, Grounding Fire, Collision C:Grounding Fire, Collision, Sinking, Flooding, Capsize, Breakaway A>B>C**
Incident Type	**3**	Kruskal-Wallis: Chi-square statistic 58.1122, P>Chi-square <0.0001 Tukey's HSD: F-value= 81.11, Pr >F <0.0001	**A:Equipment failure B:Loss of Propulsion, C:Loss of steering, Structural Failure, Near miss, Loss of Power, Loss of Anchor A>B>C**

*** = small sample size** **Bold results are statistically significant**

Events by Error Type

Events were initially categorized according to their causes, using Reason's (1997) human error framework. Confirmation of the event analysis was undertaken by requesting additional records from the U.S. Coast Guard and the Washington Department of Ecology. Even with the additional records, however, 47% (1279 events) contained insufficient information to make an error determination. Of the remaining 1426 events, 1181 were found to be due to mechanical failure and 213 were attributable to human error (Figure A-9).

Accidents were found to be caused significantly by human and organizational error (HOE), rather than mechanical failures (MF) (Table A-36); at the same time, incidents were significantly caused by mechanical failures (MF), rather than by human and organizational error (Table A-36).

A breakdown of the 1394 records with sufficient causal information is shown in Table A-37. The predominance of mechanical failures is partially a reflection of the paucity of detailed human and organizational error (HOE) and root cause data available in public data records. Note especially the drop off in HOE events after 2003, which is again though to reflect changes in reporting systems and requirements, as discussed in Section A-3.

Table A-37 shows the results of tests of the proportion of events caused by human and organizational error (HOE) compared to mechanical failure (MF): for tankers, tug-barges, cargo, WSF and fishing vessels, mechanical errors caused significantly more events than did human error at the 95% confidence level. The data and test results are shown in the Tables A-37 and A-38. Note that all of the vessel-type results are limited by small sample sizes, and by the availability of confirmatory HOE information in the public data records.

Table A-36 Wilcoxon Tests on Puget Sound Total Events, Accidents and Incidents by Error Type, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> |Z|	Direction
Total Events	**11**	66.0000	-3.9410	**<0.0001**	**MF>HOE**
Accidents	**11**	163.0000	2.3733	**0.0176**	**HOE>MF**
Incidents	**11**	66.0000	-3.9533	**<0.0001**	**MF>HOE**

*** = small sample size**

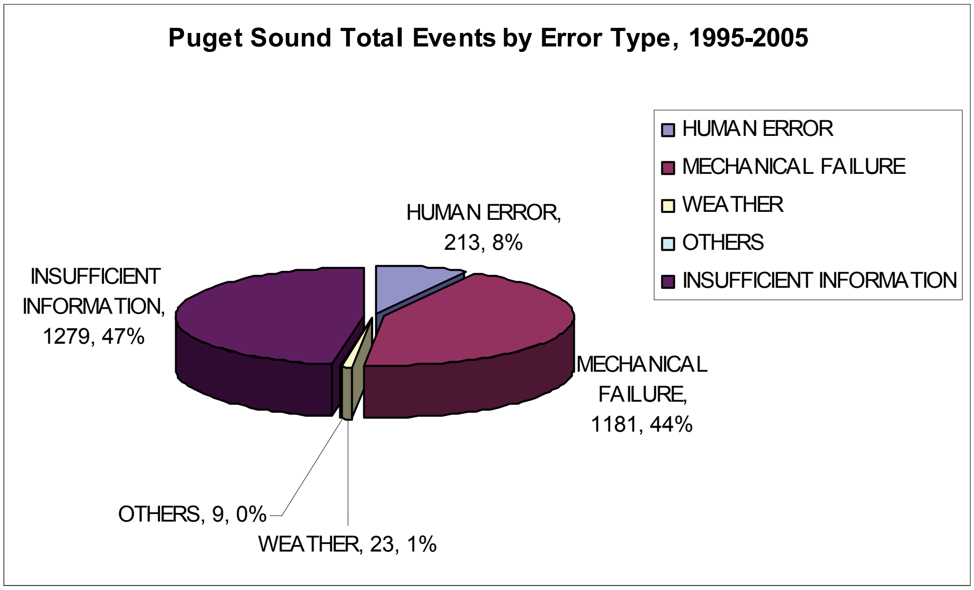

Figure A-9 Puget Sound Error Types, 1995-2005

Table A-37 Puget Sound Accidents and Incidents caused by Human and Organizational Error (HOE) and Mechanical Failure (MF); Wilcoxon test results for Tankers, Tug-Barges, Cargo Ships, WSF, and Fishing Vessels, 1995-2005

*** = small sample size** **Bold results are statistically significant**

Year	Total		Tanker		Tug-Barge		Cargo		WSF		Fishing	
	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF
1995	15*	99	1*	12*	0	2*	7*	23*	0	55	7*	7*
1996	18*	124	2*	8*	2*	5*	9*	33*	2*	72	3*	6*
1997	27*	125	3*	9*	7*	6*	10*	46	5*	60	2*	4*
1998	21*	130	2*	3*	4*	3*	7*	31*	5*	87	3*	6*
1999	12*	118	1*	8*	4*	7*	4*	31*	1*	62	2*	10*
2000	13*	123	2*	11*	4*	23*	5*	36*	2*	50	0	3*
2001	18*	155	7*	21*	5*	21*	10*	41	1*	67	0	5*
2002	21*	117	2*	14*	0	9*	7*	43	4*	44	3*	7*
2003	15*	65	2*	10*	4*	1*	6*	15*	3*	36*	0	3*
2004	5*	74	1*	12*	0	5*	3*	15*	1*	42	0	0
2005	6*	48	0*	5*	2*	9*	2*	20*	1*	14*	1*	0
Total	171	1178	23[a]	113	32[b]	91	70[c]	334	25*	589	21*[d]	51
Test Result (Direction)	**MF>HOE**		**MF>HOE**		**MF>HOE**		**MF>HOE**		**MF>HOE**		**MF > HOE**	
Wilcoxon Test Statistics	**Statistic 66.0000, Normal Approximate z= -3.9432, Pr> |z|<0.0001**		**Statistic 68.50, Normal Approximate z= -3.8049, Pr> |z|< 0.0001**		**Statistic 91.5000, Normal Approximate z= -2.2810, Pr> |z|=0.0226**		**Statistic 66.000, Normal Approximate= -3.9477, Pr> |z|< 0.0001**		**Statistic 66.0000, Normal Approximation z= -3.9533, Pr> |z|<0.0001**		**Statistic 93.00, Normal Approximate z= -2.2008, Pr> |z|=0.0278**	

[a] 23 additional events were caused by weather and 9 events were caused by 'other' reasons

[b] 42 additional events are unusual events.

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Table A-38 Puget Sound Error Types by Vessel Types, Event Types, 1995-2005

Year	Tanker Accident		Tanker Incident		Tug Accident		Tug Incident		Cargo Accident		Cargo Incident		WSF Accident		WSF Incident		Fishing Accident		Fishing Incident	
	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF	HOE	MF
1995	1*	1*	0	11*	0	0	0	2*	7*	1*	0	22*	0	0	0	55	7*	4*	0	3*
1996	1*	1*	1*	7*	2*	1*	0	4*	6*	5*	3*	28*	2*	0	0	72	3*	0	0	6*
1997	3*	1*	0	8*	7*	2*	0	4*	9*	9*	1*	37*	2*	1*	3*	59	2*	0	0	4*
1998	2*	3*	0	0	4*	1*	0	2*	6*	2*	1*	29*	4*	4*	1*	83	3*	0	0	6*
1999	0*	1*	1*	7*	4*	0	0	7*	1*	2*	3	29*	1*	1*	0	61	2*	1*	0	9*
2000	1*	0	1*	11*	4*	2*	0	21*	5*	3*	0	33*	1*	0	1*	50	0	0	0	3*
2001	1*	2*	1*	19*	4*	0	1*	21*	6*	3*	4*	38*	1*	6*	0	61	0	0	0	5*
2002	5*	3*	2*	11*	0	0	0	9*	4*	2*	3*	41	4*	2*	0	42	3*	1*	0	6*
2003	1*	1*	1*	9*	2*	0	2*	1*	6*	1*	0	14*	2*	2*	1*	34*	0	1*	0	2*
2004	0	0	1*	12*	0	2*	0	3*	1*	4*	2*	11*	1*	0	0	42	0	0	0	0
2005	0	0	0	5*	2*	1*	0	8*	2*	1*	0	19*	1*	0	0	14*	1*	0	0	0
Total	**15***	**13***	**8***	**100**	**29***	**9***	**3***	**82**	**53**	**33***	**17***	**301**	**19***	**16***	**6***	**573**	**21***	**7***	**0**	**44**

Normalizing the data by transits provided contrasting results (Table A-39). In contrast to the raw data, which showed cargo ships and tug-barges with the largest proportion of accidents by HOE, the normalized data showed tankers and cargo ships, followed by tug-barges and WSF, having the highest proportion of accidents caused by HOE. In other words, tug-barge accidents by HOE were proportionally less frequent when the normalized data were considered; similarly, tanker accidents by HOE were proportionally more frequent when the normalized data were considered. It should be noted, however, that in both the raw and normalized data, tanker accidents were characterized by small sample sizes, and because of the limited detailed accident information available, caution is advised with these results.

In the raw data, accidents due to mechanical failure occurred most frequently to cargo ships, tankers and WSF vessels. Normalizing the accidents caused by mechanical failure data dropped WSF from the most frequently occurring group; tankers and cargo ships continued to have the most frequent normalized numbers of accidents by mechanical failure over the period 1995-2005. Again, all accident data caused by mechanical failure in this analysis were characterized by a small sample size.

Raw data for incidents caused by HOE showed that cargo ships, tankers, and WSF vessels showed the highest frequency; the normalized data showed different results, as tankers alone showed the most frequency, followed by cargo vessels, tug-barges and WSF vessels. These data were also characterized by small sample sizes.

Finally, the raw data for incidents due to mechanical failure showed that these events happened most frequently to WSF vessels over the period 1995-2005, then cargo vessels, then tankers and tug-barges and fishing vessels. The normalized data again showed significant differences, with tankers and cargo ships having the highest frequency, followed by tug-barges and WSF. Note that the incidents by mechanical failure data were not characterized by small sample sizes, in contrast to the other data sets.

Normalizing the data, therefore, accounted not only for differences in transits between vessel types, but also showed that tanker events occurred most frequently for all categories, compared to the other vessel types. However, caution is advised with these results as they are all characterized by small sample sizes. Thus, whether accident or incident, HOE or mechanical cause, tanker accidents and incidents occurred most frequently, compared to other vessel types, when the accident and incident data were normalized by numbers of transits over the period 1996 – 2005.

These results may be related to the quality and availability of the nature of the data gathered, as described earlier, as well as to trends in events that occurred over the time period. Overall, it is interesting to note that even in the absence of machinery history data for any vessels, tankers and cargo ships experienced significantly more normalized incidents due to mechanical failure than did tug-barge and fishing vessels between 1995 to 2005.

Table A-39 Kruksal-Wallis and Tukey's HSD Tests on Puget Sound Error Types by Vessel Types, 1995-2005

Variable		DF	Test statistic	Direction
Raw Data	**Accident by HOE**	4	Kruksal-Wallis: Chi-square statistic = 12.6629, Pr > Chi-square=0.0130 Tukey's HSD: F-value=5.30, Pr >F =0.0012	**A: Cargo Tug-Barge B: Tug-Barge Fishing WSF Tanker* A>B**
	Accident by MF	4	Kruksal-Wallis: Chi-square statistic = 13.7505, Pr > Chi-square = 0.0081 Tukey's HSD: F-value=3.78, Pr >F =0.0093	**A: Cargo WSF Tanker B: WSF Tanker Tug-Barge Fishing A>B**
	Incidents by HOE	4	Kruksal-Wallis: Chi-square statistic = 14.9217, Pr > Chi-square= 0.0049 Tukey's HSD: F-value=4.76, Pr >F =0.0025	**A: Cargo Tanker WSF B: Tanker WSF Tug-Barge Fishing A>B**
	Incidents by MF	4	Kruksal-Wallis: Chi-square statistic = 40.6812, Pr > Chi-square<0.0001 Tukey's HSD: F-value=41.58, Pr >F <0.0001	**WSF > Cargo > Tanker= Tug-Barge= Fishing**
Normalized Data	**Accident by HOE**	3	Kruksal-Wallis: Chi-square statistic = 15.3552, Pr > Chi-square=0.0015 Tukey's HSD: F-value=5.18, Pr >F =0.0044	**A: Tanker Cargo B: Tug-Barge WSF A>B**
	Accident by MF	3	Kruksal-Wallis: Chi-square statistic = 17.8668, Pr > Chi-square = 0.0005 Tukey's HSD: F-value=8.33, Pr >F 0.0002	**A: Tanker Cargo B: Tug-Barge WSF A>B**
	Incidents by HOE	3	Kruksal-Wallis: Chi-square statistic = 13.3240, Pr > Chi-square=0.0040 Tukey's HSD: F-value=9.93, Pr >F <0.0001	**Tanker>Cargo=Tug-Barge=WSF**
	Incidents by MF	3	Kruksal-Wallis: Chi-square statistic = 24.3000, Pr > Chi-square<0.0001 Tukey's HSD: F-value=22.31, Pr >F <0.0001	**Tanker= Cargo > Tug-Barge = WSF**

*** = small sample size** **Bold results are statistically significant**

Human and Organizational Error Analysis

Detailed event records were requested from the Coast Guard and DOE to supplement the public event records. These records included CG 2692 and 835 archives from Coast Guard Headquarters and DOE accident investigation reports. Once the detailed event records were compiled and incorporated into the accident-incident database, Reason's human error framework and Shappell and Weigemann's performance shaping factors were used for analysis, as discussed in this section. Influence diagrams to illustrate BP Cherry Point tanker and ITB/ATB fleet collisions, allisions and groundings were developed (Appendix A-3). Finally, calibration events for the VTRA simulation were identified: these events included collisions, allisions and groundings for the BP Cherry Point tanker and ITB/ATB calling fleet, as described earlier.

Reason's (1997) cognitive framework of human error classifies unsafe acts into two types of activities: *errors*, which are unintended actions; and *violations*, which are intended actions (Figure A-10). Shappell and Weigemann (1997, 2001) identified errors as being of three types: *rule-based errors*, *skill-based errors*, and *knowledge-based errors*, based on Rasmussen's (1983, 1986) model of cognitive information processing. Violations can be either of two types: routine, which are common place abrogation of policies, rules or procedures that are condoned by management, or exceptional violations, which are not condoned by management.

Skill-based errors are those errors associated with failures to execute well-rehearsed actions, where there is little need for conscious decision-making (Rasmussen, 1986). Skill-based performance relies on skills that a person acquires over time and stores in memory. Skill-based errors, therefore, are largely errors of execution. Examples of skill-based errors include failures to execute a task, or to apply the correct skills to complete an assignment.

Two types of decision errors were identified by Shappell and Weigemann: rule-based and knowledge-based errors. Rule-based errors are similar to skill-based errors in that they represent failures to follow procedures, and are generally routines in nature (Rasmussen, 1986). A central difference is that people consciously fail to follow rules and procedures with which they are very familiar. Examples of rule-based errors include failures to maintain a

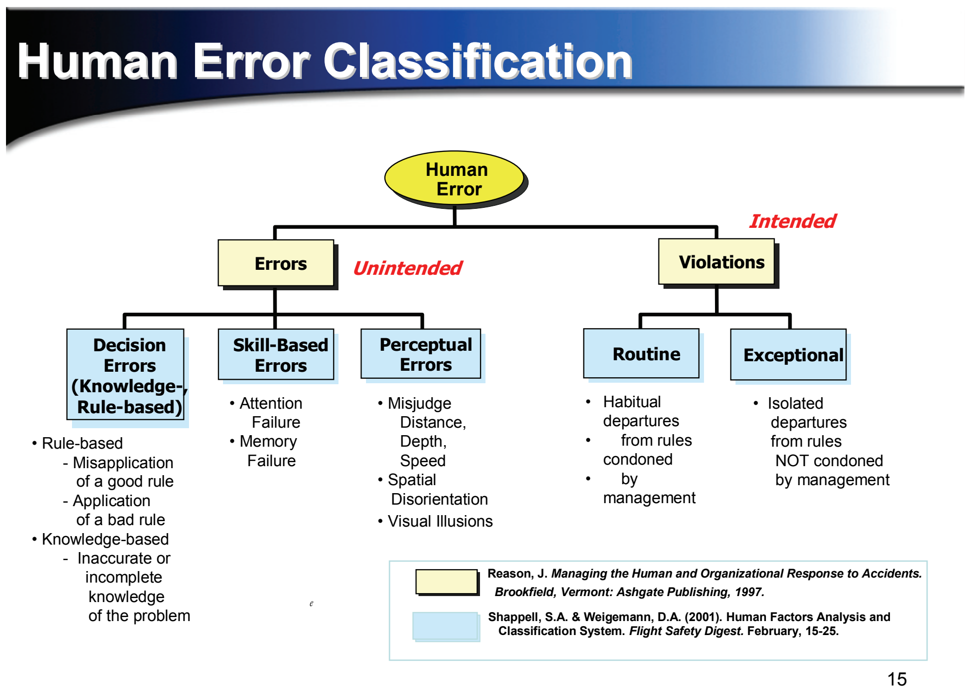

Figure A-10 Human Error Classification

piece of equipment as required, failure to follow well known company rules, and failures to follow mandatory inspection guidelines.

Errors at the knowledge level involve failures in conscious problem-solving directed towards attaining a goal (Rasmussen, 1986). Knowledge-based errors represent non-procedural behavior involving reasoning and computation, rather than rule-following (Rasmussen, 1986). Examples of knowledge-based errors include failures to reason properly, failures to utilize available information appropriately, or failures to make appropriate decisions with available information.

Perceptual errors are those that relate to failures to notice important cues or information, or to perceive information critical to decision-making. Examples of perceptual errors include failures to recognize dangerous situations, or approaches to dangerous situations; failures to recognize patterns of events that could lead to failures; or a lack of awareness of surroundings, situations or behavior that could led to adverse events.

As noted in the previous section, the human error analysis was limited by a lack of available information. Of the 2705 database events, only 53% (1426) had sufficient information to make an error determination; 47% (1279 events) had insufficient information (Figure A-9). Of the 1426 events with sufficient information for detailed error analyses, 213 of those events could be attributed to human error, while 1181 events were due to mechanical failure. In addition, 23 other events were attributed to weather conditions and 9 events were attributed to other reasons. On one hand, the proportion of human error events is a surprising result, given the often-quoted statistic that 80% of all events are due to human error; the proportion is a reflection of the paucity of detailed human error information in the event records, compared to the more available mechanical error information.

Breaking down the 213 human error events further shows that 79% (168) were unintended errors, rather than violations (32 events). Another 13 events that were characterized as due to human error in the accident records could not be described further, due to a lack of supporting or detailed information. These 13 events are counted in the HOE total of 213 events (Figure A-11), but are not counted in either of the 168 errors or 32 violations shown in Figure A-11. Of the 168 unintended errors, significantly more events (87, or 52%) were due to perceptual errors (Chi-square = 8.87, **$p = 0.012$)**, compared to decision- (36 events, 21%) or skill-based errors (45 events, 27%). As can be seen in Figure A-11, none of the error subtype data (decision error data, perceptual error data, skill-based error data) were characterized by small sample sizes.

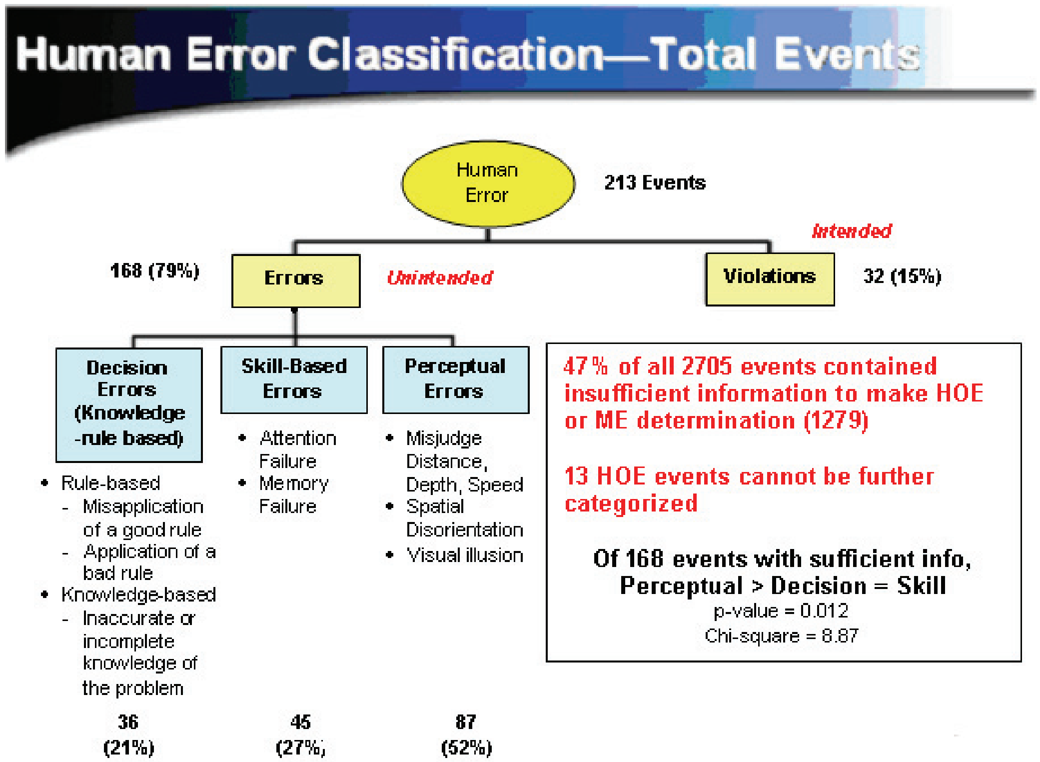

Figure A-11 Human Error Classification – Total Events in Puget Sound, 1995-2005

These trends were echoed in the accident (Figures A-12 and A-14) and incident analyses (Figures A-13 and A-15). For instance, of the 1462 accidents in Puget Sound that occurred between 1995 and 2005, only 230 accidents (15%) had sufficient information to make an error determination; 85% (1232 events) had insufficient information (Figure A-12). Of the 230 accidents with sufficient information, 137 of those accidents were due to human error, 78 were due to mechanical failure, 12 were due to weather, and 3 were due to other causes (Figure A-12). This 60:34 proportion of human error to mechanical failures for accidents is consistent with earlier accident analyses, but is inconsistent with the total event results in Figures A-9 and A-11. The inconsistency could be explained by the degree of attention paid to accident records, which typically contain more detailed analyses of human errors than incident records; however, that argument is relatively weak, given that both accident and incident data were characterized by substantial amounts of missing and insufficient data for error analyses.

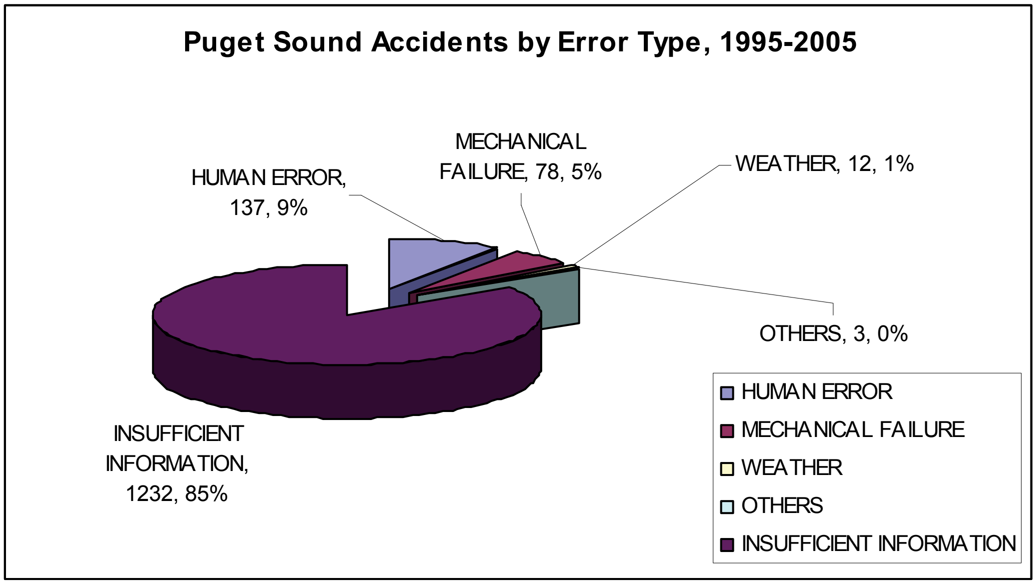

Figure A-12 Puget Sound Accident Error Types, 1995-2005

Analyzing the accidents further shows that of the 137 with sufficient information to make an error determination of human error, 85% (117 accidents) were due to unintended errors, rather than to violations (10 accidents, or 7%). 10 accident records indicated that they were due to human error, but no other supporting or descriptive information was provided in the accident record (Figure A-14). Of the 117 accidents caused by unintended errors, perceptual errors were again significantly more frequent than were accidents caused by decision- or skill-based errors (56%, Chi-square = 9.94, **p = 0.007**). However, in this analysis, the decision- and skill-based error data were characterized by small sample sizes (n = 27, 25, respectively).

The incident error analyses exhibited other trends (Figures A-13 and A-15), and were characterized by small sample sizes. In contrast to the pattern seen in the total event and accident analyses, 99% of the 1159 incidents in Puget Sound that occurred between 1995 and 2005 had sufficient information to make an error determination; only 1% did not. Thus, of the 1147 incident reports with sufficient information, 3% (34 incidents) were due to human error, while 95% (1100 incidents) were due to mechanical failure (Figure A-13). This 3:96 proportion of human error to mechanical failure accidents is consistent with the total event results in Figure A-9, and consistent with expectations associated with incidents, which are primarily equipment-related. The level of reporting detail provided in the incident records showed that mechanical failure determinations were easily identified with the available records. Few incident records reported that the mechanical failure was due to human error. This could be a reflection of the causes of incidents in Puget Sound during the reporting period, or it could be a reflection of training and reporting standards, which often emphasize identifying the broken or failing equipment or systems when filling out an incident report. In the available data, however, incidents with sufficient reported information for error analysis showed significantly more incidents due to mechanical failures, rather than caused by human error.

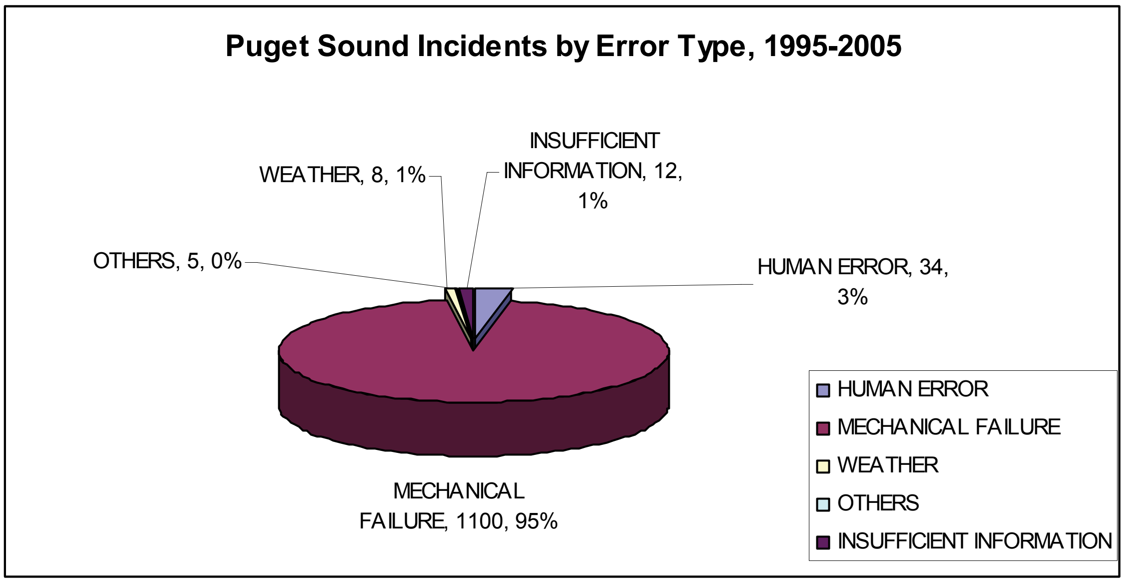

Figure A-13 Puget Sound Incidents Error Types, 1995-2005

Following Figure A-15, of the 34 incidents due to human error, most (31) had sufficient information to conduct further analysis. The pattern of error subtypes was consistent with that of events and accidents, with significantly more incidents due to perceptual errors (58%, or 18 incidents), rather than decision- (23% or 7 incidents) or skill-based errors (19%, or 6 incidents). As was noted with the accident data, however, all of the incident error subtype data were characterized by small sample sizes. This analysis, hampered as it was by insufficient information and small sample sizes, does suggest the primacy of perceptual errors as a root cause of both accidents and incidents in Puget Sound during 1995-2005.

Further investigation of accidents and incidents occurring to the BP Cherry Point calling fleet (tankers, integrated tug-barges (ITB's) and articulated tug-barges (ATB's)) during the reporting period was then undertaken. These events are of particular interest in the VTRA study, as they represent the calibration events for the vessel traffic simulation. Influence diagrams for the calibration accidents in Table A-40 are shown in Appendix A-3. A discussion of the sequence of events illustrated in the influence diagrams follows in the next section.

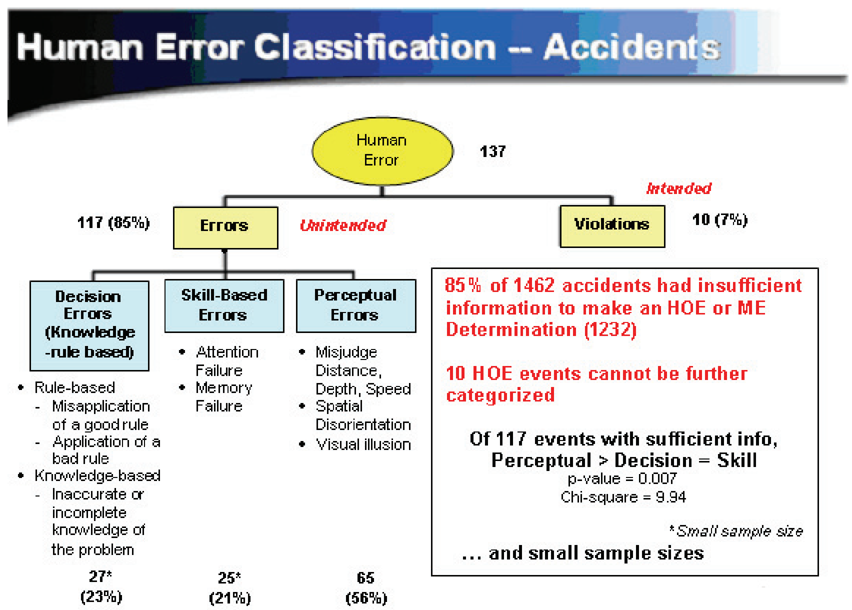

Figure A-14 Human Error Classification – Accidents in Puget Sound, 1995-2005

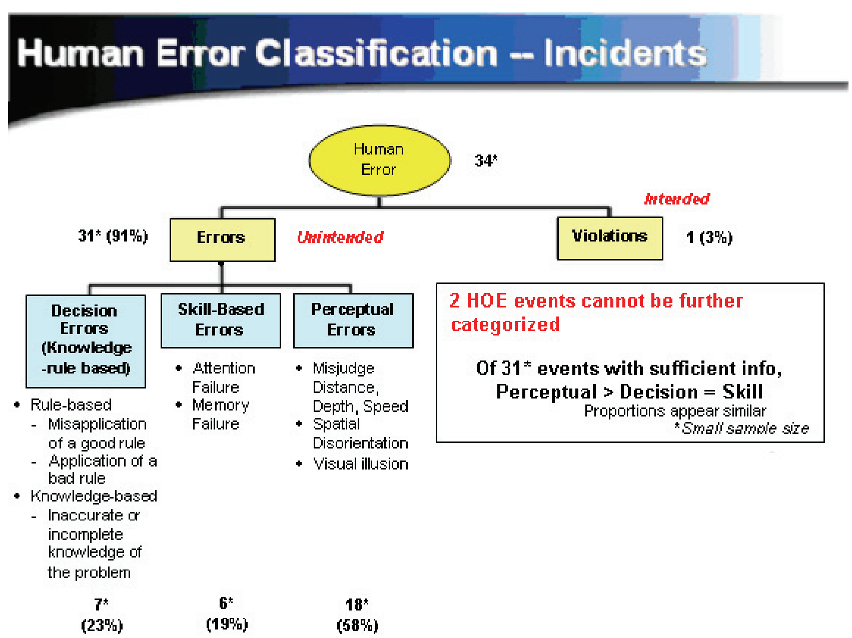

Figure A-15 Human Error Classification – Incidents in Puget Sound, 1995-2005

Error Analysis – BP Cherry Point Calling Fleet Accidents and Incidents

In order to calibrate the vessel traffic simulation, accidents and incidents occurring to tankers, ITB's and ATB's calling on BP Cherry Point between 1995-2005 were identified (Tables A-40, A-41). Calibration events for the simulation were a subset of events captured in the database—collisions, allisions and groundings. Pollution events, structural failures, capsizing, and fire and explosion accidents were not included in the calibration events or in the error analysis. Similarly, calibration incidents for the simulation included propulsion failures, steering failures and navigational equipment failures; other types of failures, and/or unusual events were not included in the calibration events or in the error analysis.

Table A-40 Calibration Accidents for Puget Sound Tankers, ITB's/ATB's, 1995-2005

Event Date	Event Time	Vessel Type	Vessel Name	Event Type	Event Type Description	Event Summary
24 Jan 1998	Null	**Tanker**	*Overseas Arctic*	**Accident**	**Allision**	Docking US Oil, hit piling bracket
14 Dec 2001	0900	**Tanker**	*Leyte Spirit*	**Accident**	**Allision**	Heavy weather, getting off dock at Ferndale; hit dock, scrape
19 Jan 2002	2140	**Tanker**	*Allegiance*	**Accident**	**Collision**	
5 Dec 1999	2035	**ITB**	*ITB New York*	**Accident**	**Grounding**	55 knot wind, anchor drag off March Point, pilot aboard Anacortes, Garth Foss respond

Table A-41 Calibration Incidents for Puget Sound Tankers, ITB's/ATB's, 1995-2005

Event Date	Event Time	Event Year	Vessel Type	Vessel Name	Event Type	Event Type Description
17 Mar 2002		2002	Tanker	Allegiance	Incident	Propulsion failure
13 Oct 1999		1999	Tanker	Angelo D'Amato	Incident	Propulsion failure
13 Dec 1999		1999	Tanker	Antiparos	Incident	Propulsion failure
25 Sept 2001		2001	Tanker	British Hawk	Incident	Propulsion failure
20 April 97		1997	Tanker	Chevron Mississippi	Incident	Propulsion failure
29 Dec 2000		2000	Tanker	Chevron Mississippi	Incident	Propulsion failure
17 Oct 2001		2001	Tanker	Great Promise	Incident	Propulsion failure
18 Oct 2001		2001	Tanker	Great Promise	Incident	Propulsion failure
18 July 2004		2004	Tanker	Gulf Scandic	Incident	Propulsion failure
12 Nov 2004	0010	2004	Tanker	Gulf Scandic/British Harrier	Incident	Propulsion failure
21 Jan 2001		2001	Tanker	HMI Brenton Reef	Incident	Propulsion failure
30 April 01		2001	Tanker	JoBrevik	Incident	Propulsion failure
11 July 1996		1996	Tanker	Kenai	Incident	Propulsion failure
13 Sept 1995		1995	Tanker	Overseas Alaska	Incident	Propulsion failure
24 Dec 1995		1995	Tanker	Overseas Boston	Incident	Propulsion failure
9 June 1996		1996	Tanker	Overseas Boston	Incident	Propulsion failure
8 July 1997		1997	Tanker	Overseas Boston	Incident	Propulsion failure
10 Nov 2005		2005	Tanker	Overseas Puget Sound	Incident	Propulsion failure
1 Feb 2001		2001	Tanker	Overseas Washington	Incident	Propulsion failure
12 Dec 2001		2001	Tanker	Overseas Washington	Incident	Propulsion failure
28 April 02		2002	Tanker	Pacific Sound	Incident	Propulsion failure
25 Dec 1995		1995	Tanker	Paul Buck	Incident	Propulsion failure
15 April 02		2002	Tanker	Polar Endeavor	Incident	Propulsion failure
7 Sept 2002		2002	Tanker	Polar Endeavor	Incident	Propulsion failure
7 May 2002		2002	Tanker	Polar Trader	Incident	Propulsion failure

Event Date	Event Time	Event Year	Vessel Type	Vessel Name	Event Type	Event Type Description
16 Dec 1995		1995	Tanker	Prince William Sound	Incident	Propulsion failure
18 Dec 2002		2002	Tanker	Prince William Sound	Incident	Propulsion failure
31 July 1999		1999	Tanker	SeaRiver Baytown	Incident	Propulsion failure
7 Oct 2003		2003	Tanker	SeaRiver Baytown	Incident	Propulsion failure
20 Mar 2003		2003	Tanker	SeaRiver Hinchinbrook	Incident	Propulsion failure
16 Aug 1996		1996	Tanker	Stavenger Oak	Incident	Propulsion failure
17 Mar 2001		2001	Tanker	Alfios	Incident	Steering failure
22 Oct 1996		1996	Tanker	Arcadia	Incident	Steering failure
3 Nov 1995		1995	Tanker	Berge Eagle (LPG)	Incident	Steering failure
14 June 1995		1995	Tanker	Carla Hills	Incident	Steering failure
1 Dec 2000		2000	Tanker	Kanata Hills	Incident	Steering failure
13 Oct 1999		1999	Tanker	New Endeavor	Incident	Steering failure
15 June 2000		2000	Tanker	Overseas New York	Incident	Steering failure
25 July 2001		2001	Tanker	Overseas Washington	Incident	Steering failure
20 Mar 2000		2000	Tanker	Chevron Mississippi	Incident	Steering failure
18 July 2000		2000	Tanker	Samuel L. Cobb	Incident	Steering failure
2 Nov 1997		1997	Tanker	SeaRiver Baton Rouge	Incident	Steering failure
28 Feb 2003		2003	Tanker	Denali	Incident	Nav equipment failure
11 Jan 2002		2002	Tanker	Overseas Chicago	Incident	Nav equipment failure
16 May 2004		2004	Tanker	Polar California	Incident	Nav equipment failure
23 May 2004		2004	Tanker	Polar California	Incident	Nav equipment failure
25 Feb 2005		2005	Tanker	Polar California	Incident	Nav equipment failure
28 Feb 2004		2004	Tanker	Polar California	Incident	Nav equipment failure
21 Mar 2004		2004	Tanker	Polar Discovery	Incident	Nav equipment failure
28 Apr 2004		2004	Tanker	Polar Discovery	Incident	Nav equipment failure
01 Mar 2004		2004	Tanker	Sea Reliance	Incident	Nav equipment failure
17 April 04		2004	Tanker	Tonsina	Incident	Nav equipment failure
24 Aug 2002		2002	ATB	ATB-550/Sea Reliance	Incident	Propulsion failure
28 July 2001		2001	ITB	ITB Baltimore	Incident	Propulsion failure
18 June 2000		2000	ITB	ITB Groton	Incident	Propulsion failure
27 May 2001		2001	ITB	ITB Groton	Incident	Steering failure
24 Aug 2002		2002	ATB	Sea Reliance	Incident	Steering failure
26 Sep 2002		2002	ITB	ITB MOBIL	Incident	Nav equipment failure
08 Nov 2004		2004	ATB	Ocean Reliance	Incident	Nav equipment failure

Table A-41 Calibration Incidents for Puget Sound Tankers, ITB's/ATB's, 1995-2005

A total of 4 calibration accidents -- 3 tanker accidents (2 allisions, 1 collision) and 1 ITB/ATB accident (1 grounding)-- were identified during the reporting period 1995-2005. A total of 59 calibration incidents – 31 tanker propulsion failures, 11 tanker steering failures, 10 tanker navigational equipment failures, 3 ITB/ATB propulsion failures, 2 ITB/ATB steering failures, and 2 ITB/ATB navigational equipment failures – were also identified during the reporting period 1995-2005. Influence diagrams for the tanker and ITB/ATB calibration accidents in Table A-40, as well as for two incidents and one unusual event, are shown in Appendix A-3. Notably, all tanker and ITB/ATB accidents occurred during the winter months and several involved human response to events occasioned by severe weather.

Substantial information was available for two calibration events—the collision between the 612' single hull inbound tanker *Allegiance* and the escort tug *Sea King* on 19 January 2002 and the grounding of the *ITB New York* after she dragged anchor at March Point on 5 December 1999. Coast Guard 2692 and MISLE records, as well as Washington State Department of Ecology and VTS Puget Sound incident records, were available for these events, as were court documents from resulting litigation, articles from local newspapers, and reports from *Lloyd's Casualty Reporting*.

As can be seen in the Appendix A-3 influence diagram, the *Allegiance – Sea King* collision event was characterized by communication, perception and medical history problems during the inbound night transit to Tesoro. In subsequent litigation, the *Allegiance* was found not to have provided adequate lookout and the *Sea King* tug was found to have lost situational awareness. No pilot error was noted during the event. As a result of the collision, the tug *Sea King* sustained significant structural damage and two crew members were injured; the vessel was dewatered, the tug captain surrendered his license on medical grounds, and significant economic losses were sustained.

The *ITB New York* grounding illustrates how situations such as a dragging anchor can compound quickly for a light single hull ITB at anchor in winds of 40-55 knots. Timely assistance was rendered by three nearby assist tugs that ultimately pulled the vessel afloat. The vessel was in communication with the VTS, who provided assistance positioning and repositioning the vessel. Vessel damage was negligible in this event, or no personnel casualties were noted.

In both of these accidents, situational awareness played a significant role in determining the course and outcome of the event. In one case, lack of situational awareness led to an adverse outcome with personnel injuries, substantial economic losses and vessel structural damage; in the other case, situational awareness enhanced by additional resources on assist vessels and the VTS resulted in mitigated economic, personnel and structural consequences.

The allision of the double hull Bahamian Teekay Shipping tanker *Leyte Spirit* at the Philips Petroleum dock in Ferndale on the morning of 14 December 2001 shows a pattern similar to the *ITB New York* grounding: assist tug and pilot resources were available to the vessel, which was attempting to leave the Ferndale dock with winds gusting from 40-50 knots. The allision occurred when the pilot tried to get the vessel off the dock. In the first attempt to leave the dock, a line from the *Leyte Spirit* to the tug *Sea King* parted, and the vessel allided with the dock. In the second attempt, the *Leyte Spirit* was able to get away from the berth with no further damage to the vessel or the dock. Sufficient information was available about the allision, as the event was captured in Coast Guard 2692 and MISLE reports, as well as Washington State Department of Ecology and Puget Sound Pilot incident reports. In this event, as with the *ITB New York* grounding, the mitigated outcome occasioned by severe weather was influenced by the human and mechanical response resources available (pilots, assist tugs).

Unfortunately, there was less information available for the remaining calibration events. As can be seen in Appendix A-3, there was little information in the Coast Guard MISLE and Puget Sound Pilot Commission records to provide description of the events associated with the allision of the single hull tanker *Overseas Arctic* when she was docking at U.S. Oil in Tacoma on 24 January 1998. Similarly, the influence diagram for the tanker *Overseas Boston* pollution event on 13 January 2002 at the Tosco pier in Ferndale shows that the lack of available information extends to pollution events, although, in general, records are more complete for pollution events than for some allisions, propulsion failures, steering failures or navigational equipment failures.

The influence diagram for the inbound double hull tanker *Gulf Scandic*'s propulsion failure on the night of 12 November 2004 shows that even when event records include data from the Coast Guard 2692 and MISLE files, as well as from the Washington State Department of Ecology, there may be little available information with which to undertake an error analysis. More information was available for the unusual event that occurred on 11 February 2002, to the double bottom tanker *Blue Ridge,* which was underway from Port Angeles and heaving up anchor when the propeller became fouled, resulting in substantial propeller and tanker damage.

In short, the influence diagram analysis echoes the descriptive statistic analysis presented in Figures A-11 – A-15, which showed substantial missing and incomplete information with respect to human and organizational error analyses, even when multiple sources were used to corroborate and analyze the event. This is a recurring problem in maritime accident and incident analyses and suggests the need for greater attention to standardized data capture, collection, sharing and analysis across organizations with interest in improved maritime safety.

Summary of Significant Event Results, 1995-2005

A summary of significant total event frequencies in the Puget Sound VTRA Accident-Incident database is given in Table A-42, which shows that there are significant differences in the normalized total events by vessel type. For normalized total events, 1995-2005, cargo and tanker ships had a statistically higher frequency of events than did tug-barges and Washington State Ferries (WSF). Normalizing the data by transits altered the results of the events by vessel type analysis so as to reflect the surrogate exposure risk suggested by the vessel type's number of transits.

Analysis of events by year showed that 1995 and 1997-2002 had a higher event frequency than other years. However, after normalization by transit data, slightly different test results were observed: years 1998-2002 had a statistically higher number of total events than did other years. Different test results between raw data and normalization data also can be found in events by season. Tests on raw data by season showed that summer and winter had a statistically higher number of total events than did autumn and spring. However, when the data were normalized by transits, autumn and spring had statistically higher numbers of total events than did winter and summer, in part because of the increase in transits during the summer and winter seasons.

Analysis of events by location showed that South Puget Sound had the highest number of events, compared to other locations. One of the important reasons may be that more transits occurred in South Puget Sound than other locations because of the numerous ferry runs. Furthermore, inbound vessels had a statistically higher number of events than did outbound vessels. More transits for inbound vessels in Puget Sound can account for this result. Also, vessels classed by ABS had the highest number of events, compared to those classed by other class societies since many more vessels sailing in Puget Sound belong to ABS.

Analysis of events by vessel flag showed that U.S. flagged vessels had a higher total event frequencies than did those from foreign flags, and among foreign flag vessels, vessels from Panama had a statistically higher event frequency than those from any other foreign flags.

Analysis of events by error type showed that events were significantly caused by mechanical failures (MF) rather than by human and organizational error (HOE), although the analysis was impacted by the lack of data for error analysis. The significant statistical results are summarized in Table A-42. In all cases except incidents caused by mechanical failures, the data were characterized by insufficient information for error analyses.

Table A-42 Summary of Significant Puget Sound Maritime Events, 1995-2005

Test	Results	Test Used	Statistics	Direction
Events by Vessel Type*	**Cargo and WSF ships had higher event frequencies than other vessel types**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 34.2814, Pr > Chi-square <0.0001 Tukey's HSD: F value= 19.24, Pr>F <0.0001	**A: Cargo = WSF** **B: WSF Fishing** **C: Fishing Tug-barge** **D: Tanker** **A>B>C>D**
Events by Vessel Type (normalized)*	**Cargo and tanker ships had higher normalized event frequencies than tug/barge and WSF ships**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 32.9020, Pr > Chi-square <0.0001 Tukey's HSD: F value= 19.17, Pr>F <0.0001	**Cargo=Tanker> Tug-barge=WSF**
Accident-Incident Pyramids by Vessel Type	**Fishing had the highest accident-incident ratio among five vessel types**	Kruskal-Wallis Pair Wilcoxon	Chi-square statistic 38.9369, DF = 4, Pr > Chi-square <0.0001	**Fishing > Tug-barge > Cargo >Tanker = WSF**
Events by Year	**Years 1997-2002 had higher events than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 60.1687, Pr > Chi-square <0.0001 Tukey's HSD: F-value=11.27, Pr > F<0.0001	**A:2001 2002 1999 2000 1997 1998 1995 B:2002 1999 2000 1997 1998 1995 1996 C: 1999 2000 1997 1998 1995 1996 2004 D: 2000 1997 1995 1996 2004 2003 E:2005** A>B>C>D>E
Events by Year (normalized)	**Years 1999-2002 had higher normalized events than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 59.0563, Pr > Chi-square <0.0001 Tukey's HSD: F-value=13.40, Pr >F <0.0001	**A:2001 2002 2000 1999 1998 B:2002 2000 1999 1998 1997 2004 C:2000 1999 1998 1997 2004 1996 D:1999 1998 1997 2004 1996 2003 E:2005** A>B>C>D>E

Test	Results	Test Used	Statistics	Direction
Events by Location*	**South Puget Sound had a higher number of events than other locations**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 80.7694, Pr>Chi-square<0.0001 Tukey's HSD: F-value= 81.20, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, West Strait of Juan de Fuca, East Strait of Juan de Fuca C: West Strait of Juan de Fuca, East Strait of Juan de Fuca, Guemes Channel, San Juan Islands, Saddlebag, Cherry Point, Rosario Strait, Haro Strait A>B>C**
Events by Season*	**Summer and Winter had higher event frequencies than Autumn and Spring did**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 29.3489, Pr>Chi-square <0.0001 Tukey's HSD: F-value=56.31, Pr >F <0.0001	**Summer=Winter>Autumn =Spring***
Events by Season (Normalized)*	**Autumn and Spring had higher normalized event frequencies than Winter and Summer did**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 13.2963, P>Chi-square =0.0040 Tukey's HSD: F-value=6.71, Pr >F =0.0012	**Autumn=Spring> Winter =Summer***
Events by Flag (U.S. Flag vs. Non U.S. Flag)	**Vessels from U.S. flag had higher frequency than those from Non-U.S. flags**	Wilcoxon	Statistic 184.0000, Normal Approximation z= 3.7768, Pr> z=0.0002	**U.S.>Non U.S.**
Events by Non U.S.-Flag*	**Vessels from Panama had higher event frequency than those from other foreign flags**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 21.0342, P>Chi-square =0.0026 Tukey's HSD: F-value= 32.65, Pr >F <0.0001	**Panama> Bahamas*= Canada* =Cyprus* =Liberia* = Russia* =Singapore***
Events by Class Society*	**Vessels classed by ABS had statistically higher number of total events than those from other class societies.**	Krussal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 30.4518, P>Chi-square <0.0001 Tukey's HSD: F-value=34.16, Pr >F <0.0001	**ABS>NV*=NK*=LR***
Events by Direction (Inbound/Outbound)*	**Inbound vessels had significantly higher event frequencies than outbound vessels**	Wilcoxon	Statistic 172.500, Normal Approximate z= 3.0474, Pr> z=0.0023	**Inbound*>Outbound***
Events by Error Type (HOE vs. Mechanical)*				
	Events caused by MF had higher number of frequency than those caused by HOE	Wilcoxon	Statistic 68.0000, Normal Approximation z= -3.8965, Pr> z<0.0001	**MF>HOE**
Events by Error Type for different vessel types*	**Tankers had more events by MF than by HOE**	Wilcoxon	Statistic 77.5000, Normal Approximation z= -3.2350, Pr> z=0.0012	**MF>HOE**
	Tug/barges had more events by MF than by HOE	Wilcoxon	Statistic 95.5000, Normal Approximation z= -2.1130, Pr> z=0.0345	**MF>HOE**
	Cargo ships had more events by MF than by HOE	Wilcoxon	Statistic 70.000, Normal Approximation z= -3.7164, Pr> z=0.0002	**MF>HOE**
	WSF had more events by MF than by HOE	Wilcoxon	Statistic 66.0000, Normal Approximation z= -3.9863, Pr> z<0.0001	**MF>HOE**
	Fishing had more events by MF than by HOE	Wilcoxon	**Statistic 95.5000, Normal Approximation z=-1.9914, Pr> z=0.0464**	**MF>HOE**

*** = small sample size Bold results are statistically significant**

Accidents in Puget Sound, 1995-2005

A summary of significant accident results from the Puget Sound VTRA Accident-Incident database is given in Table A-43, which shows that the number of accidents gradually increased in Puget Sound between 1996 and 2002; in 2002, accidents began to decline. Explanations for why this decline might be related to reporting and organizational changes, rather than trends in accident frequency.

Accident frequencies between 1995 and 2005 were assessed using the Kruskal-Wallis and Tukey's HSD tests which found that 1995 and 1997-2004 showed significant differences in terms of the numbers of accidents which occurred. These differences were significant at the 95% confidence interval. Normalized accident frequencies showed similar patterns, with the years 1997-2002 and 2004 significantly different than the remainder of the years; these results were significant at the 95% confidence interval.

Analysis of accidents by season showed that summer and winter had a higher number of accidents than spring and autumn. However, after data normalization, no statistical difference was found among the four seasons since more transits occurred during summer and winter seasons. This trend was different than the observed event frequency in Puget Sound, 1995-2005, which saw more normalized events in spring and autumn.

Analysis of accidents by vessel type showed that cargo ships and fishing vessels had the highest accident frequencies among the five vessel types; when the results were normalized, only cargo vessels had the highest accident frequency among the five vessel types. Analysis of accidents by location showed that South Puget Sound had a higher number of accidents than other locations in Puget Sound, most likely because more transits occurred in South Puget Sound than other areas.

Analysis of accidents by vessel flag showed that there were a statistically higher number of accidents occurring to U.S. flag vessels, compared to foreign flag vessels. Among the foreign flag vessels, those from Panama, Canada and Russia had a higher accident frequency than any other foreign flag vessels. Accident data by vessel owner and class society was tested, which showed that Foss, Crowley, U.S. Navy, U.S. Coast Guard, and Olympic Tug and

Barge vessels had the highest accident frequencies and vessels classed by ABS had a statistically higher number of accidents than did those of other class societies. Neither owner nor class data were normalized by vessel transits, as that data were not available. Previous analyses showed significant differences between results with raw and normalized data; those patterns may have also been observed in the vessel owner and class analysis.

Finally, accidents caused by pollution had a statistically higher frequency than those caused by Allision, Grounding, Fire, Collision, Sinking, Flooding, Capsize, Breakaway, and Salvage. Analysis of accidents by error type showed that accidents caused by human error had a statistically higher number than those caused by mechanical failure.

Table A-43 Summary of Significant Statistical Test Results on Puget Sound Accident Frequency, 1995-2005

Test	Results	Test Used	Statistics	Direction
Accidents by Vessel type*	**There were statistical differences in accident frequency among five vessel types**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 39.0843, Pr > Chi-square <0.0001 Tukey's HSD: F Value =26.82, Pr>F <0.0001	**A: Cargo Fishing B: Fishing Tug-Barge C: WSF Tanker* A>B>C**
Accidents by Vessel Type (normalized)*	**Cargo ships had the highest normalized accident frequency**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 27.3205, Pr > Chi-square <0.0001 Tukey's HSD: F Value =26.53, Pr>F <0.0001	**A: Cargo B: Tanker* Tug-Barge C: Tug-Barge WSF A>B>C**
Accidents by Year	**Year 2005 had significantly lower accidents than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 51.6289, Pr > Chi-square <0.0001 Tukey's HSD: F-value=8.88, Pr >F <0.0001	**A:2002 1999 2001 2000 1995 1997 1998 2004 2003 B:2000 1995 1997 1998 2004 2003 1996 C: 2005** A>B>C
Accidents by Year (normalized)	**Years 1996 and 2005 have lower number of normalized accidents than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 51.1032, Pr > Chi-square =0.0017 Tukey's HSD: F-value=9.94, Pr >F <0.0001	**A:2002 2001 2000 1999 1998 2004 1997 B: 2001 2000 1999 1998 2004 1997 2003 C: 1998 2004 1997 2003 1996 D: 1996 2005** A>B>C>D
Accidents by Location*	**South Puget Sound had higher number of accident than other locations**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 79.5272, Pr > Chi-square <0.0001 Tukey's HSD: F-value =79.24, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, West Strait of Juan de Fuca, Saddlebag, Cherry Point, East Strait of Juan de Fuca, Guemes Channel C: West Strait of Juan de Fuca, Saddlebag, Cherry Point, East Strait of Juan de Fuca, Guemes Channel, San Juan Islands, Haro Strait A>B>C**
Accidents by Season*	**Summer and Winter had higher accident frequency than Autumn and Spring did**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 29.4899, P>Chi-square <0.0001 Tukey's HSD: F-value=69.62, Pr >F <0.0001	**Summer=Winter > Autumn = Spring***

Test	Results	Test Used	Statistics	Direction
Accidents by Season (normalized)*	**No statistical differences for normalized accident frequency exist among four seasons**	Kruskal-Wallis	Kruskal-Wallis: Chi-square statistic 1.0841, P>Chi-square =0.7809 Tukey's HSD: F-value=0.78, Pr >F =0.5154	**N/A**
Accidents by Flag (U.S. Flag vs. Non U.S. Flag)	**Vessels with U.S. flag had higher accident frequency than those from Non-U.S foreign flag.**	Wilcoxon	Statistic 179.5000, Normal Approximation z= 3.4871, Pr> z=0.0005	**U.S.>Non U.S.**
Accidents by Non U.S.-Flag*	**Vessels from Panama/Canada/Russia have higher accident frequency than those from other foreign flags**	Kruskal-Wallis Wilcoxon	Kruskal-Wallis: Chi-square statistic 21.5897, P>Chi-square =0.0014	**Panama= Canada= Russia> Bahamas =Cyprus =Singapore**
Accidents by Owner*	**Vessels from different owners had statistical differences in accident frequency**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 20.9822, P>Chi-square =0.0010 Tukey's HSD: F-value=4.60, Pr >F=0.0016	**A: Foss Crowley US Navy USCG Olympic Tug & Barge** **B: Olympic Tug & Barge Clipper A>B**
Accidents by Class Society*	**Vessels classed by ABS had statistically higher accident frequencies than those from other class societies.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 26.6617, P>Chi-square <0.0001 Tukey's HSD: F-value= 54.05, Pr >F <0.0001	**ABS>NV=NK=LR**
Accidents by Accident type*	**Accidents caused by pollution had statistically higher number of frequency than accidents caused by other types.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 69.4233, P>Chi-square <0.0001 Tukey's HSD: F-value= 78.22, Pr >F <0.0001	**A: Pollution** **B: Allision, Grounding Fire, Collision C: Grounding Fire, Collision, Sinking, Flooding, Capsize, Breakaway** **A>B>C**
Accidents by Error Type	**Accidents caused by HOE had statistically higher number of frequency than accidents caused by MF**	**Wilcoxon**	**Statistic 164.0000, Normal Approximation z= 2.4722, Pr> z=0.0134**	**HOE>MF**

*** = small sample size** **Bold results are statistically significant**

Incidents in Puget Sound, 1995-2005

Analysis of incidents in Puget Sound between 1995 and 2005 showed that the number of incidents gradually increased in Puget Sound between 1996 and 2001; in 2002, incidents began to decline. Explanations for why this decline might be related to reporting and organizational changes, rather than trends in incident frequency, have already been presented.

Incident frequencies between 1995 and 2005 were assessed using the Kruskal-Wallis and Tukey's HSD tests, which found that years from 1996 to 2002 showed significant differences in terms of the numbers of incidents which occurred, compared to the other years. These differences were significant at the 95% confidence interval. Normalized incident frequencies showed similar patterns, as years 1996 to 2002 still had a higher number of normalized incidents than other years.

Analysis of raw numbers of incidents by season showed that vessels had a higher number of incidents in summer and winter than in spring and autumn. However, tests on normalized incident data showed that spring and autumn had a higher number of incidents than summer and winter, consistent with trends in the normalized accident data reported in the previous section.

Analysis of raw numbers of incidents by vessel type showed that WSF had the highest number of incidents, then cargo ships, and then tankers, tug-barges and fishing vessels. Normalization of the data showed different results: tankers had higher incident frequencies than other vessel types, then cargo vessels, then tug-barges and WSF. This is another example of data with different results using the raw and normalized data.

Analysis of incidents by location showed that South Puget Sound had the highest incident frequency, compared to other locations, similar to the results seen in the total event and accident analysis. Vessels had higher incident frequencies during the day than the night, and U.S. flag vessels had a higher number of incidents than those from foreign flags. Among the foreign flag vessels, vessels from Panama had the highest number of incidents, compared to those from other foreign countries. Clipper, Crowley, Foss, U.S. Navy and Olympic Tug &

Barge vessels had higher numbers of incidents compared to other vessel owners, and vessels classed by ABS had a statistically higher incident frequency than those belonging to other class societies. Neither the owner nor ABS data were normalized by vessel transits, as that data were not available. Previous analysis showed significant differences between results with raw and normalized data; those differences might have been observed in the owner and ABS normalized data analysis, had that data been available. Analysis of incidents by direction showed that inbound vessels had a higher incident frequency than outbound vessels.

Incidents caused by equipment failure were statistically more frequent than those caused by loss of propulsion, loss of steering, near miss, structural failure, and loss of power. Analysis of incidents by error type showed that incidents caused by MF occurred more frequently than those caused by HOE. The same result was observed for all vessels types.

The summary of significant statistical test results for incidents is shown in Table A-44.

Table A-44 Summary of Significantly Statistical Test Results for Puget Sound Incidents, 1995-2005

Test	Results	Test Used	Statistics	Direction
Incidents by Vessel Type*	**WSF had the highest normalized incident frequency**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 40.7493, Pr > Chi-square <0.0001 Tukey's HSD: F Value= 39.92, Pr>F <0.0001	**WSF> Cargo> Tanker= Tug-Barge = Fishing**
Incidents by Vessel Type (normalized) *	**Tankers had the highest normalized incident frequency**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 24.1537, Pr > Chi-square <0.0001 Tukey's HSD: F Value= 20.99, Pr>F <0.0001	**Tanker>Cargo>Tug-Barge=WSF**
Incidents by Year *	**Years 1996-2002 had higher incidents than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 56.7266, Pr> Chi-square < 0.0001, Tukey's HSD: F-value=8.61, Pr >F <0.0001	**A:2001 2000 1998 1996 1997 1999 2002 B: 2000 1998 1996 1997 1999 2002 1995 C:1997 1999 2002 1995 2004 D: 1995 2004 2003 2005** A>B>C>D
Incidents by Year (normalized)*	**Years 2001, 2000, 1998, 2002, 1997, 1996, and 1999 had higher normalized incidents than other years.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 51.1060, Pr> Chi-square < 0.0001 Tukey's HSD: F-value=8.97, Pr >F <0.0001	**A: 2001 2000 1998 2002 1997 1996 1999 B: 1998 2002 1997 1996 1999 2004 C: 1999 2004 C:1999 2004 2003 D: 2004 2003 2005** A>B>C>D
Incidents by Location	**South Puget Sound had higher number of incidents than other locations**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 79.2347, Pr > Chi-square <0.0001 Tukey's HSD: F-value= 44.79, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, West Strait of Juan de Fuca, East Strait of Juan de Fuca C: West Strait of Juan de Fuca, East Strait of Juan de Fuca, San Juan Islands, Guemes Channel D: East Strait of Juan de Fuca, San Juan Islands, Guemes Channel, Saddlebag, Cherry Point, Rosario Strait, Haro Strait A>B>C>D**
Incidents by Season*	**Summer and Winter had higher incident frequency than Autumn and Spring did**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 27.5853, P>Chi-square < 0.0001 Tukey's HSD: F-value=21.83, Pr >F <0.0001	**Summer=Winter > Spring= Autumn**
Incidents by Season (Normalized)*	**Spring and Autumn had higher normalized incident frequency than Winter and Summer did**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 14.9298, P>Chi-square =0.0019 Tukey's HSD: F-value=8.07, Pr >F =0.0004	**Spring=Autumn> Winter =Summer**

Test	Results	Test Used	Statistics	Direction
Incidents by Time of Day*	**Incidents occurred more often during day than night**	Wilcoxon	Statistic 156.500, Normal Approximation z= 1.9739, Pr> z=0.0484	**Day>Night**
Incidents by Flag (U.S. Flag vs. Non U.S. Flag)	**Vessels from U.S. flag had higher incidents frequency than those from Non-U.S. flag**	Wilcoxon	Statistic 187.0000, Normal Approximation z= 3.9795, Pr> z<0.0001	**U.S.>Non U.S.**
Incidents by Non U.S.-Flag*	**Vessels from Panama had higher incident frequency than those from other foreign flags**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 23.0145, P>Chi-square =0.0011 Tukey's HSD: F-value =17.20, Pr >F <0.0001	**Panama> Bahamas= Canada =Cyprus =Liberia = Russia =Singapore**
Incidents by Owner*	**Vessels from different owners had statistical different incident frequency**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 11.6234, P>Chi-square =0.0440 Tukey's HSD: F value 2.56, Pr>F 0.0445	**A: Clipper, Crowley, Foss, US Navy, Olympic Tug & Barge** **B: Crowley, Foss, U.S. Navy, Olympic Tug & Barge, USCG A>B**
Incidents by Class Society*	**Vessels classed by ABS had statistically higher incident frequency than those from other class societies.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 28.0562, P>Chi-square <0.0001 Tukey's HSD: F-value= 20.21, Pr >F <0.0001	**ABS>NV=NK=LR**
Incidents by Direction (Inbound/Outbound)*	**Inbound vessels had significant higher incidents frequency than outbound vessels**	Wilcoxon	Statistic 170.500, Normal Approximation z= 2.9421, Pr> z=0.0033	**Inbound>Outbound**
Incidents by Incident type	**Incidents caused by equipment failure had statistically higher frequency than incidents caused by other types.**	Kruskal-Wallis Tukey's HSD	Kruskal-Wallis: Chi-square statistic 58.1122, P>Chi-square <0.0001 Tukey's HSD: F-value= 81.11, Pr >F <0.0001	**A: Equipment failure B: Loss of Propulsion, C: Loss of steering, Structural Failure, Near miss, Loss of Power, Loss of Anchor** **A>B>C**
Incidents by Error Type	Incidents caused by MF has statistically higher frequency than incidents caused by HOE	**Wilcoxon**	**Statistic 66.0000, Normal Approximation z= -3.9863, Pr> z<0.0001**	**MF>HOE**

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Appendix A-1
Puget Sound Tanker Events, Accidents and Incident Analysis
1995-2005

Puget Sound Tanker Events, Accidents and Incidents, 1995-2005

In this section, an analysis of tanker events between 1995 and 2005, as recorded in the Puget Sound VTRA Accident-Incident database, is undertaken. Tankers include crude oil tankers, product tankers, LPG tankers, LNG tankers, combined chemical and oil tankers, chemical tankers, and Military Sealift Command tankers. 171 tanker events are in the database: 35 are accidents (20.47%), 111 are incidents (64.9%), and the remaining 25 records are unusual events. The tanker accident-incident pyramids for years 1995-2005 are shown in Figure A-16. Note that there are small sample sizes for all tanker accidents and unusual events.

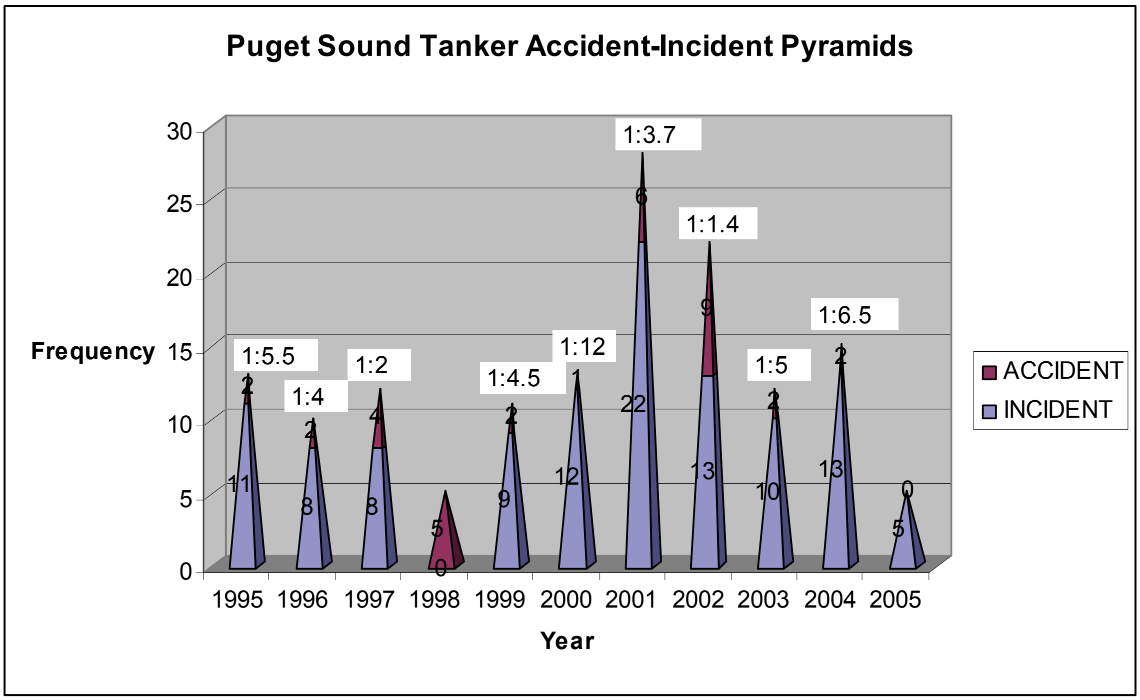


Figure A-16 Tanker Accident-Incident Ratios, 1995-2005

Tanker Events by Year, 1995-2005

Total tanker transit data (1996-2005) and tanker events, accidents, incidents, and unusual events (1995-2005) are given in Table A-45 and Figure A-17 below. The normalized data are also shown in Table A-46.

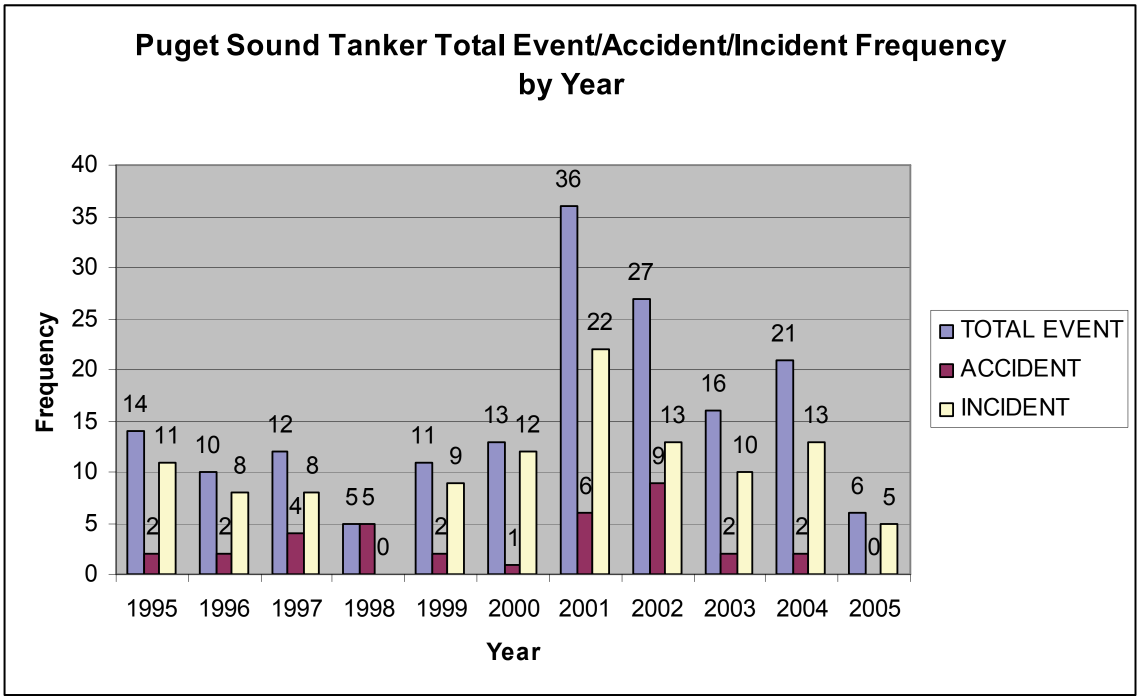


Figure A-17 Tanker Total Events, Accidents, and Incidents by Year, 1995-2005

Table A-45 Tanker Normalized Total Events, Accidents, and Incidents, 1995-2005 * = small sample size

Year (1)	Transit (2)		Total events (3)		Normalized events (4)=(3)/(2)	Accidents (5)		Normalized Accidents (6)=(5)/(2)	Incidents (7)		Normalized Incidents (8)=(7)/(2)	Unusual events (9)	
	N	%	N	%		N	%		N	%		N	%
1995	N/A	N/A	14*	8.2	N/A	2*	5.7	N/A	11 *	9.9	N/A	1 *	0.04
1996	2001	9.5	10 *	5.8	0.004998	2 *	5.7	0.001	8 *	7.2	0.003998	0	0
1997	2289	10.9	12 *	7.0	0.005242	4 *	11.4	0.001747	8 *	7.2	0.003495	0	0
1998	2107	10.0	5 *	2.9	0.002373	5 *	14.3	0.002373	0	0	0	0	0
1999	2095	9.9	11*	6.4	0.005251	2 *	5.7	0.000955	9 *	8.1	0.004296	0	0
2000	2557	12.1	13*	7.6	0.005084	1 *	2.9	0.000391	12*	10.8	0.004693	0	0
2001	2145	10.2	36 *	21.1	0.016783	6 *	17.1	0.002797	22*	19.8	0.010256	8 *	32
2002	1848	8.8	27 *	15.8	0.01461	9 *	25.7	0.00487	13 *	11.7	0.007035	5 *	20
2003	1889	9.0	16*	9.4	0.00847	2*	5.7	0.001059	10*	9	0.005294	4 *	16
2004	2031	9.6	21 *	12.3	0.01034	2 *	5.7	0.000985	13 *	11.7	0.006401	6 *	24
2005	2103	10.0	6 *	3.5	0.002853	0	0	0	5 *	4.5	0.002378	1 *	4
Total	**21065**	**100**	**171**	**100**	**N/A**	**35**	**100**	**N/A**	**111**	**100**	**N/A**	**25***	**100**

From Figure A-17, it can be seen that years 2001 and 2002 had the greatest number of tanker events in Puget Sound. Kruskal-Wallis and Tukey's HSD tests showed that there were statistical differences between normalized events and incidents from 1996-2005, with years 2002 and 2003 having the events and incidents (Table A-46). However, Wilcoxon tests on the data found that no statistical differences before and after year 2000 (Table A-47).

Table A-46: Kruskal-Wallis and Tukey's HSD Tests on Total Events, Accidents, and Incidents Frequencies by Year, 1995-2005

Variable		DF	Test Statistics	Direction
Raw Data	**Total Events**	10	Kruskal-Wallis: Chi-square statistic 24.1119, Pr > Chi-square =0.0073 Tukey's HSD: F-value=3.62, Pr >F =0.0003	A:2001 2002 2004 2003 1995 B: 2002 2004 2003 1995 2000 1997 1999 1996 2005 1998 **A>B**
	Accidents*	10	Kruskal-Wallis: Chi-square statistic 12.4000, Pr > Chi-square =0.2592 Tukey's HSD: F-value=1.27, Pr >F =0.2549	N/A
	Incidents	10	Kruskal-Wallis: Chi-square statistic 23.1115, Pr > Chi-square =0.0103 Tukey's HSD: F-value=2.22, DF = 10, Pr >F =0.0207	A: 2001 2004 2002 2000 1995 2003 1999 1996 1997 2005 B: 2004 2002 2000 1995 2003 1999 1996 1997 2005 1998 **A>B**
Normalized Data	**Total Events**	9	Kruskal-Wallis: Chi-square statistic 23.9004, Pr > Chi-square =0.0045 Tukey's HSD: F-value=3.69, Pr >F =0.0005	A: 2002 2003 2005 1996 2004 B: 2003 2005 1996 2004 1998 2001 1997 2000 1999 **A>B**
	Accidents*	9	Kruskal-Wallis: Chi-square statistic 9.2947, Pr > Chi-square=0.4105 Tukey's HSD: F-value=1.02, Pr >F 0.4263	N/A
	Incidents	9	Kruskal-Wallis: Chi-square statistic 22.5624, Pr > Chi-square =0.0073 Tukey's HSD: F-value=2.50, DF = 9, Pr >F =0.0120	A: 2002 2003 1996 2005 2001 2004 1998 1997 2000 B: 2003 1996 2005 2001 2004 1998 1997 2000 1999 **A>B**

*** = small sample size** **Bold results are statistically significant**

Table A-47 Wilcoxon Test Result for Tanker Raw and Normalized Events, Accidents, and Incidents before and after Year 2000

Variable		N*	Test statistic	Normal approximate Z	Two-sided Pr> $\|Z\|$	Direction
Raw Data	**Total events**	5/6*	20.0000	-1.8257	0.0679	N/A
	Accidents*	5/6*	32.0000	0.3830	0.7017	N/A
	Incidents	5/6*	20.0000	-1.8341	0.0666	N/A
Normalized Data	**Total events**	5*	19.0000	-1.7756	0.0758	N/A
	Accidents*	5*	25.0000	-0.5222	0.6015	N/A
	Incidents	5*	19.000	-1.7756	0.0758	N/A

*** = small sample size** **Bold results are statistically significant**

Tanker Events by Location

Total tanker events, accidents, incidents, and unusual events, and percent for different geographic areas, are given in Figure A-18 and Table A-48.

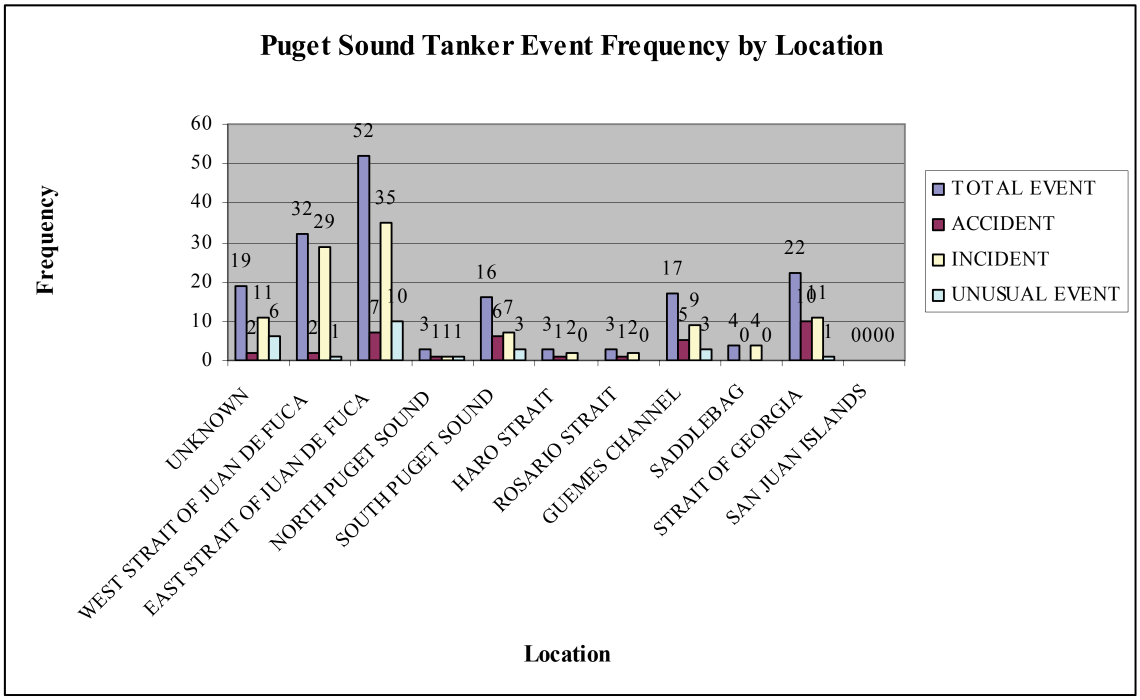


Figure A-18 Puget Sound Tanker Events, Accidents and /Incidents by Location, 1995-2005

Table A-48 Tanker Events, Accidents, and Incidents, by Location, 1995-2005

Zone	Total Tanker Events		Tanker Accidents		Tanker Incident		Tanker Unusual Event	
	N*	%	N*	%	N*	%	N	%
West Strait of Juan de Fuca	32	18.7	2*	5.71	29*	26.13	1*	4
East Strait of Juan de Fuca	52	30.4	7*	20	35	31.53	10*	40
North Puget Sound	3*	1.75	1*	2.86	1*	0.9	1*	4
South Puget Sound	16*	9.36	6*	17.14	7*	6.31	3*	12
Haro Strait/Boundary Pass	3*	1.75	1*	2.86	2*	1.80	0*	0
Rosario Strait	3*	1.75	1*	2.86	2*	1.80	0*	0
Guemes Channel	17*	9.94	5*	14.28	9*	8.11	3*	12
Saddlebags	4*	2.34	0*	0	4*	3.60	0*	0
Strait of Georgia/Cherry Point	22*	12.87	10*	28.57	11*	9.91	1*	4
San Juan Islands	0*	0	0*	0	0*	0	0*	0
Unknown	19*	11.1	2*	5.71	11*	9.91	6*	24
Total	**171**	**100**	**35**	**100**	**111**	**100**	**25***	**100**

N: Number of total events, accidents, incidents, and unusual events;%: Percent of event frequency for every geographic area.
*** = small sample size** **Bold results are statistically significant**

Table A-48 and Figure A-18 show that the areas West and East Strait of Juan de Fuca are areas that had the most of events for tankers in Puget Sound from year 1995-2005. This is a significantly different result than for other vessel types, which showed most events occurring in South Puget Sound. The East and West Straits of Juan de Fuca are areas of particular interest, as vessels in the East Straits are often engaged in northward transits to refineries. A Wilcoxon test of the tanker events, accidents, and incidents in the East and West Straits of Juan de Fuca, however, found no difference in numbers of events for these two areas (Table A-49).

Further analysis using the Kruskal-Wallis and Tukey's HSD tests showed that there were statistical differences in total events, accidents, and incident frequencies among the 10 geographic areas (Table A-50). Table A-50 shows that tankers have a similar geographic distribution for events and incidents, as both have the highest frequencies in the East and West Straits of Juan de Fuca. Note, however, that tanker accident locations differ, and occur most frequently in the Cherry Point, East Strait of Juan de Fuca, and South Puget Sound areas. All data are limited by small sample sizes.

Table A-49: Wilcoxon Tests on Tanker Events, Accidents, and Incidents Frequencies between East and West Strait of Juan de Fuca, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Tanker Events	11	114.0000	-0.8279	0.4078	N/A
Accidents	11	109.0000	-1.4102	0.1585	N /A
Incidents	11	122.0000	-0.3002	0.7640	N/A

Table A-50: Kruskal-Wallis and Tukey's HSD Tests on Tanker Events, Accidents, and Incidents Frequencies by Location, 1995-2005 * = small sample size

Variable	DF	Test Statistics	Direction
Total Events	9	Kruskal-Wallis: Chi-square statistic 47.5930, Pr > Chi-square <0.0001 Tukey's HSD: F-value=7.36, Pr >F <0.0001	A: East Strait of Juan de Fuca, West Strait of Juan de Fuca B: West Strait of Juan de Fuca, Cherry point, Guemes Channel, South Puget Sound, Saddlebag C: Cherry point, Guemes Channel, South Puget Sound, Saddlebag, North Puget Sound, Rosario Strait, Haro Strait, San Juan Islands **A>B>C**
Accidents*	9	Kruskal-Wallis: Chi-square statistic 22.4411, Pr > Chi-square =0.0076 Tukey's HSD: F-value=2.65, Pr >F =0.0086	A: Cherry Point, East Strait of Juan de Fuca, South Puget Sound, Guemes Channel, West Strait of Juan de Fuca, Rosario Strait, North Puget Sound, Haro Strait B: East Strait of Juan de Fuca, South Puget Sound, Guemes Channel, West Strait of Juan de Fuca, Rosario Strait, North Puget Sound, Haro Strait, Saddlebag, San Juan Islands **A>B**
Incidents	9	Kruskal-Wallis: Chi-square statistic 46.0565, Pr > Chi-square <0.0001 Tukey's HSD: F-value=8.31, Pr >F <0.0001	A: East Strait of Juan de Fuca, West Strait of Juan de Fuca B: West Strait of Juan de Fuca, Cherry point C: Cherry point, Guemes Channel, South Puget Sound, Saddlebag, Haro Strait, Rosario Strait, North Puget Sound, San Juan Islands **A>B>C**

*** = small sample size**

Events in the East and West Straits of Juan de Fuca before and after the year 2000 were also tested to determine whether events had different frequencies before and after 2000, when the Cherry Point dock was built. A Wilcoxon test showed that no difference was found in events in the West Strait and East Strait (Table A-51). Note that these results are also limited by small sample sizes.

Table A-51 Wilcoxon Tests on Tanker Events, Accidents, and Incidents Frequencies in East and West Strait of Juan de Fuca before and after 2000, 1995-2005

Variable		N*	Test statistic	Normal approximate Z	Two-sided Pr> $\|Z\|$	Direction
West Strait of Juan de Fuca	Tanker Events	11*	28.0000	-0.3685	0.7125	N/A
	Accidents*	11*	30.5000	0.1361	0.8918	N/A
	Incidents	11*	28.5000	-0.2796	0.7798	N/A
East Strait of Juan de Fuca	Tanker Events	11*	20.0000	-1.8599	0.0629	N/A
	Accidents*	11*	32.5000	0.5118	0.6088	N/A
	Incidents	11*	20.5000	-1.7545	0.0793	N/A

* = small sample size Bold results are statistically significant

Tanker Events by Season

Figures A-19 and A-20 show raw and normalized total events, accidents, and incidents by season, from which it can be seen that the 2002 and 2003 seasons had higher raw and normalized total events than those in other years.

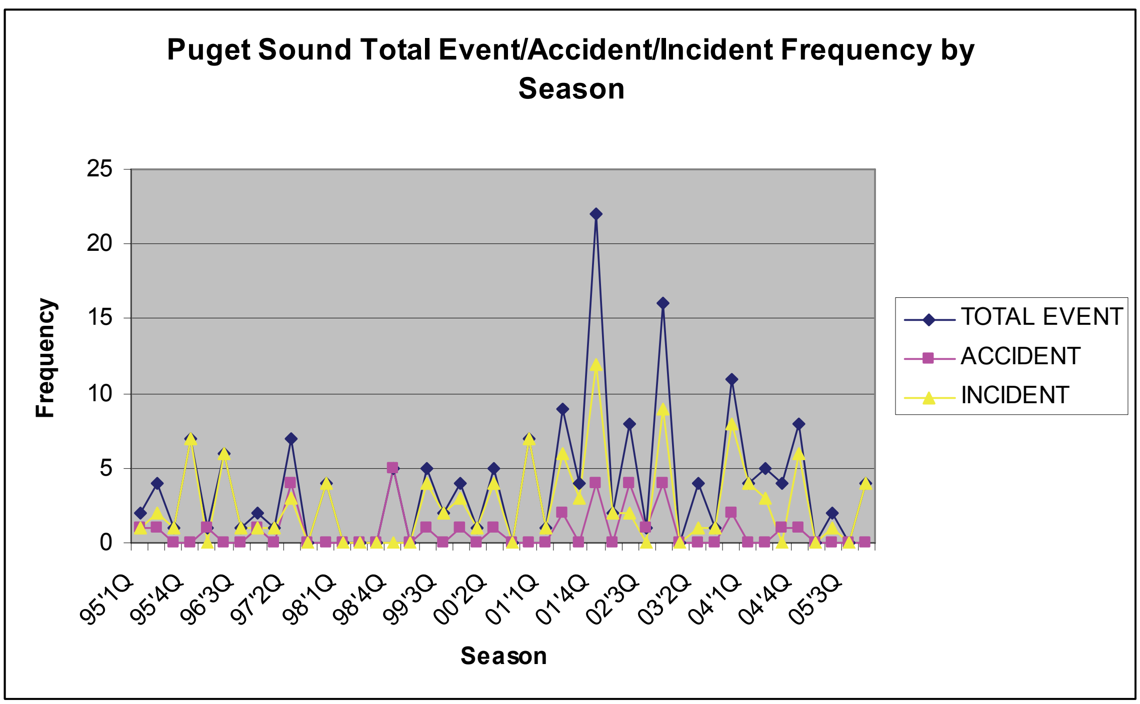


Figure A-19 Raw Puget Sound Tanker Events, Accidents and Incidents, 1995-2005

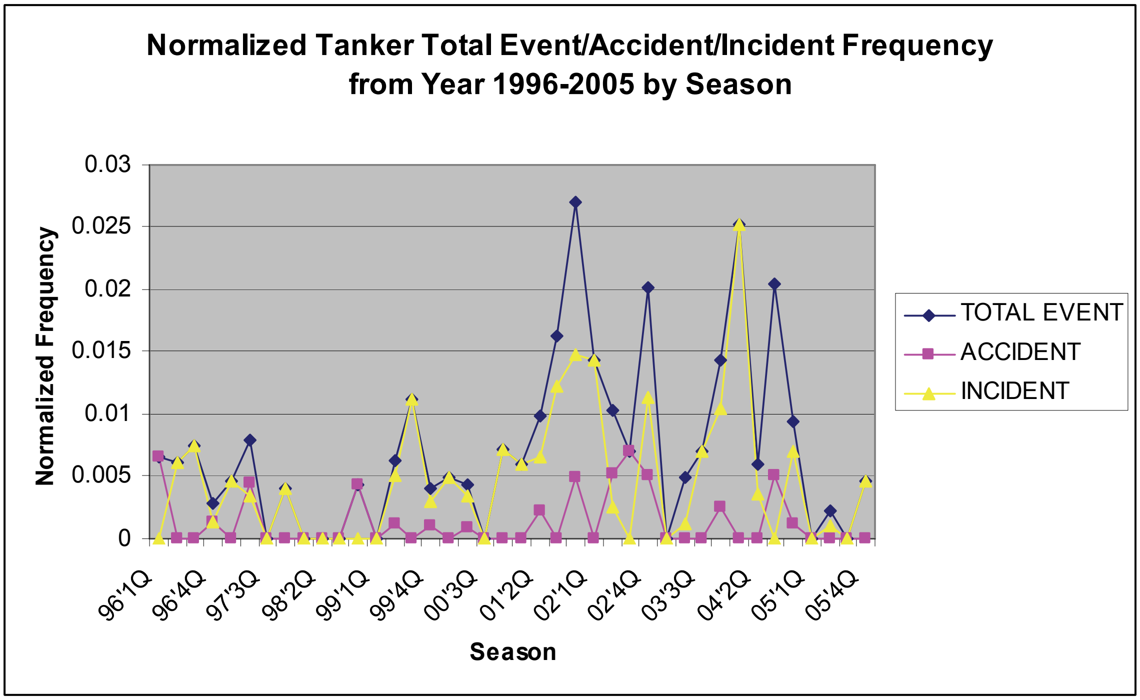


Figure A-20 Normalized Puget Sound Tanker Events, Accidents and Incidents, 1996-2005

Analysis using Kruskal-Wallis and Tukey's HSD tests showed that although tankers had different total event and incident frequencies among the four seasons in the raw data analysis, no statistical difference for normalized tanker events, accidents, or incidents existed among the four seasons (Table A-52). Note that the data are limited by small sample sizes.

Table A-52 Kruskal-Wallis and Tukey's HSD tests of Raw and Normalized Event, Accident, and Incident Frequencies for Tanker by Season * =small sample size

Variable		DF	Test statistic	Direction
Raw Data	Total Events	3	Kruskal-Wallis: Chi-square statistic 24.8965, D Pr> Chi-square <0.0001 Tukey's HSD: F-value=10.79, Pr >F =0.0001	**A: Winter Summer** **B: Summer Autumn** **C: Autumn Spring** **A>B>C**
	Accidents*	3	Kruskal-Wallis: Chi-square statistic 9.6246, Pr> Chi-square =0.0220 Tukey's HSD: F-value=3.84, Pr >F =0.0166	**A: Winter Summer** **B: Summer Spring Autumn** **A>B**
	Incidents	3	Kruskal-Wallis: Chi-square statistic 18.9876, Pr> Chi-square =0.0003 Tukey's HSD: F-value=11.62, Pr >F <0.0001	**A: Winter** **B: Summer Spring Autumn** **A>B**
Normalized Data	Total Events	3	Kruskal-Wallis: Chi-square statistic 1.3870, P> Chi-square =0.7086 Tukey's HSD: F-value=0.83, Pr >F =0.4859	N/A
	Accidents*	3	Kruskal-Wallis: Chi-square statistic 6.1219, P> Chi-square =0.1058 Tukey's HSD: F-value=0.71, Pr >F =0.5544	N/A
	Incidents	3	Kruskal-Wallis: Chi-square statistic 2.8621, P> Chi-square =0.4134 Tukey's HSD: F-value=0.78, Pr >F=0.5146	N/A

A seasonality index was constructed to assess the likelihood of tanker events, accidents and incidents in Puget Sound by season between 1995 and 2005. This analysis showed that events in summer and winter seasons occurred more often than events in the spring and autumn seasons, similar to the observations for all vessels reported in earlier sections. For normalized events, the winter season had more than other seasons (Table A-53). This contrasts with the results for all vessels in VTRA Accident-Incident database, which showed that events occurred more often in summer and winter than in the spring and autumn; for normalized events, spring and winter had slightly more events than summer and winter (Table A-20). This suggests that normalized tanker accidents had different seasonality patterns than all other vessels taken together for the period 1995-2005. Table A-53 also shows that normalized tanker events, accidents, and incidents happened more frequently in winter, compared to other three seasons between 1995-2005. However, spring and autumn had more incidents than did the summer and winter seasons for all vessel types between 1995 and 2005 (Table A-20). Therefore, normalized tanker events showed different seasonality patterns compared to all vessels taken together, 1996-2005. For raw data, tanker total events, accidents, and incidents show the same seasonality patterns as all vessels taken together in the period of 1995-2005.

Table A-53 Raw and Normalized Seasonal Index for Tanker Total Events, Accidents, and Incidents, 1995-2005

Season	Raw Seasonal Index		
	Total Events	Accidents	Incidents
Spring	0.28	0.23	0.36
Summer	1.29	1.49	1.15
Autumn	0.33	0.23	0.29
Winter	2.11	2.06	2.20
	Normalized Seasonal Index		
Spring	0.81	0.49	1.10
Summer	0.82	1.06	0.82
Autumn	0.98	0.91	0.88
Winter	1.39	1.54	1.38

Tanker Events by Time of Day

Tanker events by time of day in the Puget Sound VTRA database were assessed by day and night, as shown in the Table A-54. The large amount of missing data in Table A-54 suggests this analysis needs to be revalidated with a more complete data set.

Table A-54: Puget Sound Tanker Event Type by Time of Day, 1995-2005

Time	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
Day	52	30.4	13*	37.1	36	32.4
Night	26*	15.2	6*	17.1	16*	14.4
Null	93	54.4	16*	45.8	59	53.2

*** = small sample size**

A Wilcoxon analysis of the data in Table A-54 shows that tankers had no different accident frequencies during the day and the night in Puget Sound between years 1995-2005. However, total events and incidents occurred more often during the day than the night for tanker ships (Table A-55). Note that those results are limited by small sample size and by the large amount of missing data.

Table A-55 Wilcoxon Tests of Tanker Events, Accidents, and Incidents, by Time of Day, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	11	158.0000	2.1181	**0.0342**	**Day>Night**
Accidents*	11	147.5000	1.4788	0.1392	N/A
Incidents	11	161.5000	2.3555	**0.0185**	**Day>Night**

*** = small sample size** **Bold results are statistically significant**

Tanker Events by Vessel Flag

Although most vessels in Puget Sound are U.S. flag vessels, some are foreign-flag vessels. The distribution of total events, accidents, and incidents between U.S. vessels and foreign flag vessels is shown in Table A-56. Note all of that the data is limited by small sample sizes.

Table A-56 U.S. and Non-U.S. Flag Tanker Events, Accidents, and Incidents, 1995-2005

Year	Total events		Accidents		Incidents	
	US	Non-US	US	Non-US	US	Non-US
1995	11*	3*	1*	1*	9*	2*
1996	7*	3*	1*	1*	6*	2*
1997	11*	1*	3*	1*	8*	0
1998	4*	1*	4*	1*	0	0
1999	7*	4*	2*	0	5*	4*
2000	10*	2*	0	1*	10*	1*
2001	25*	8*	2*	4*	18*	4*
2002	16*	8*	5*	4*	10*	3*
2003	12*	0	2*	0	10*	0
2004	13*	3*	1*	1*	10*	2*
2005	6*	0	0	0	5*	0
Total	122	33	21	14*	91	18*
Percent	71.3	19.3	60	40	82.0	16.2

*** = small sample size**

Table A-56 shows that accidents occurred to U.S. and non-U.S. flag tankers at almost the same rate, while incidents occurred to U.S. flag tankers more than the non-U.S. flag tankers. A Wilcoxon test showed that U.S. flag tankers had a higher number of total events and incidents than those non U.S. flag tankers. However, no difference in accident frequency occurred between U.S. and Non U.S. flag tankers (Table A-57). Note that the data are limited by small sample sizes.

Table A-57 Wilcoxon Tests on Tanker Events, Accidents, and Incident Frequencies by Vessel Flag, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\|Z\|$	Direction
Tanker Events	11	178.5000	3.4243	**0.0006**	**U.S.>Non U.S.**
Accidents*	11	144.0000	1.2004	0.2300	N/A
Incidents	11	178.0000	3.4167	**0.0006**	**U.S.>Non U.S.**

*** = small sample size**

Total tanker events, accidents, and incidents by different foreign flags were assessed, as seen in Table A-58. No statistically significant results were found in this analysis, which was limited by small sample size.

Table A-58 Tanker Total Event/Accident/Incident by Vessel Flag, 1995-2005

Vessel Flag	Tanker Events		Accidents		Incidents		Unusual Events	
	N	%	N	%	N	%	N	%
U.S.	122	71.3	21*	60	91	82.0	10*	40
Bahamas	2*	1.2	1*	2.9	1*	0.9	0	0
Greece	3*	1.8	1*	2.9	2*	1.8	0	0
Isle of Man	4*	2.4	2*	5.7	2*	1.8	0	0
Liberia	8*	4.8	5*	14.3	3*	2.7	0	0
Marshall Islands	2*	1.2	0		2*	1.8	0	0
Panama	5*	2.9	3*	8.6	2*	1.8	0	0
Norway	3*	1.8	0		3*	2.7	0	0
Singapore	2*	1.2	1*	2.9	0		1*	4
Other	20*	11.7	1*	2.9	5*	4.5	14*	56
Total	171	100	35	100	111	100	25	100

*** = small sample size**

Tanker Events by Vessel Owner

The total events, accidents, and incidents frequencies for vessels from different owners are showed in the Table A-59.

Table A-59 Tanker Events, Accidents, Incidents, Unusual Events by Vessel Owner, 1995-2005

Vessel Owner	Tanker Events		Accidents		Incidents		Unusual Events	
	N	%	N	%	N	%	N	%
SeaRiver Maritime	19*	11.1	2*	5.7	16*	14.4	1*	4
Polar Tankers	11*	6.4	2*	5.7	9*	8.1	0	0
Overseas Shipholding	25*	14.6	5*	14.3	19*	17.1	1*	4
Nordic American Tanker Shipping	4*	2.3	2*	5.7	2*	1.8	0	0
Marine Transport Corp	5*	2.9	0	0	2*	1.8	3*	12
Lightship Tankers	4*	2.3	1*	2.9	3*	2.7	0	0
Keystone Shipping	19*	11.1	2*	5.7	16*	14.4	1*	4
Chevron USA / Chevron Shipping	9*	5.3	1*	2.9	8*	7.2	0	0
ARCO	5*	2.9	2*	5.7	3*	2.7	0	0
SHIPCO 670 / Alaska Tanker Company (ATC)	13*	7.6	3*	8.6	9*	8.1	1*	4
Other	57	33.3	15*	42.9	24*	21.6	18*	72
Total	171	100	35	100	111	100	25	100

*** = small sample size**

Table A-59 shows that Overseas Shipholding, Keystone Shipping and SeaRiver Maritime are the owners of tanker vessels that had the most event frequencies in Puget Sound between 1995 and 2005. A Kruskal-Wallis analysis, however, shows that tankers from these three owners had no statistical difference in total event, accident, and incident frequencies (Table A-60). These data were all characterized by small sample sizes.

Table A-60 Kruskal-Wallis Tests of Tanker Events, Accidents, and Incident Frequencies by Vessel Owner, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	2	Kruskal-Wallis: Chi-square statistic 1.2356, P> Chi-square =0.5722	N/A
Accidents	2	Kruskal-Wallis: Chi-square statistic 0.3101, P> Chi-square =0.8501	N/A
Incidents	2	Kruskal-Wallis: Chi-square statistic 1.3920, P> Chi-square =0.4847	N/A

Tanker Events by Direction

Tankers sailing in Puget Sound can be classified as inbound vessels and outbound vessels. Total tanker events, accidents, and incidents for both inbound tankers and outbound tankers are shown in Table A-61. The statistical tests on the tanker events, accidents, or incidents by direction are not available because of small sample size.

Table A-61 Puget Sound Tanker Events by Direction, 1995-2005

Direction	Total Events		Accidents		Incidents	
	N	%	N	%	N	%
Inbound	23*	13.5	1*	2.9	21*	18.9
Outbound	4*	2.3	0	0	4*	3.6
Null	144	84.2	34*	97.1	86	77.5

*** = small sample size**

Tanker Events by Hull Type

There are four hull types for tankers in the database: single hull, double hull, double sides, and double bottoms, as seen in Figure A-21 and Table A-62. Missing information was classified as "unknown". A Wilcoxon test of the Table A-62 data shows that double hull vessels had significantly higher numbers of total events, accidents, and incidents than single hull tankers (Table A-63). Note that this data, too, is limited by small sample sizes.

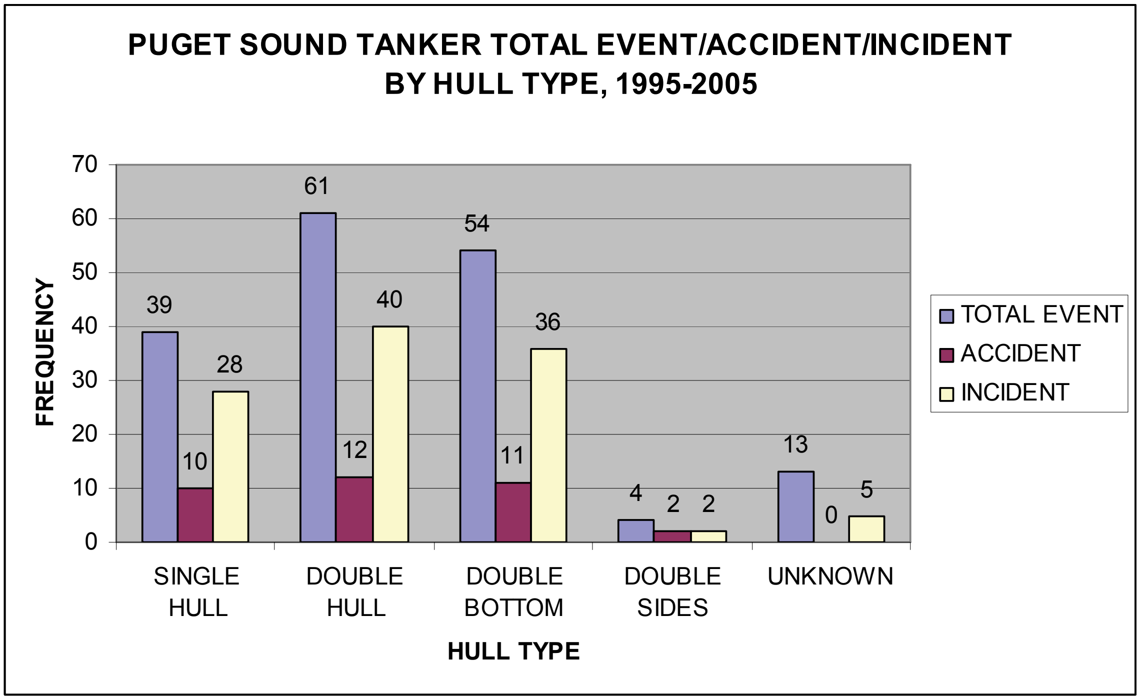


Figure A-21 Tanker Accidents, Incidents and Unusual Events by Hull Types, 1995-2005

Table A-62 Tanker Accident/Incident/Unusual Event Frequency by Hull Type, 1995-2005

Event	Single Hull	Double Hull	Double Sides	Double Bottom	Unknown
Accidents	10*	12*	2*	11*	0
Incidents	28*	40	2*	36*	5*
Unusual Events	1*	9*	0	7*	8*
Total	39*	61	4*	54	13*

*** = small sample size**

Table A-63 Wilcoxon Tests of Tanker Events, Accidents, and Incidents by Hull Type, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Tanker Events	11	91.0000	-2.3390	**0.0193**	**Double Hull* >Single Hull***
Accidents	11	94.5000	-2.2226	**0.0262**	**Double Hull* >Single Hull***
Incidents	11	93.0000	-2.2206	**0.0264**	**Double Hull* >Single Hull***

*** = small sample size**

Tanker Events by Vessel Size

Tankers were classified by deadweight tonnage to determine if events were associated with differing vessel sizes. Vessel sizes were classified as three categories: below 40,000; 40,000~80,000; and above 80,000 DWT (Table A-64).

Table A-64 Tanker Events by Vessel Size, 1995-2005

Vessel Size	Tanker Events		Accidents		Incidents	
	N	%	N	%	N	%
Below 40,000 DWT	71	41.5	20*	55.6	45	40.54
40,000-80,000 DWT	71	41.5	12*	33.3	50	45.05
80,000 DWT above	20*	11.7	3*	8.3	14*	12.61

*** = small sample size**

A Kruskal-Wallis analysis of the Table A-64 data showed statistical differences between total events, accidents, and incidents for tankers of different sizes (Table A-65). Tankers less than 80,000 gross tons had significantly higher numbers of events, accidents and incidents than did larger tankers, those that were above 80000 gross tons. Note also that these results are limited by small sample sizes.

Table A-65 Kruskal-Wallis and Tukey's HSD tests of Tanker Events, Accidents, and Incidents by Vessel Size, 1995-2005

Variable	DF	Test statistic	Directions
Tanker Events	2	Kruskal-Wallis: Chi-square statistic 13.2427, P> Chi-square =0.0013 Tukey's HSD: F-value=6.28, Pr >F =0.0053	(Below 40000)= (40000-80000)> (80000 above)*
Accidents	2	Kruskal-Wallis: Chi-square statistic 8.3235, P> Chi-square =0.0156 Tukey's HSD: F-value=4.66, Pr >F =0.0173	A: (Below 40000), (40000-80000) B: (40000-80000), (80000 above) **A>B***
Incidents	2	Kruskal-Wallis: Chi-square statistic 10.4913, P> Chi-square =0.0053 Tukey's HSD: F-value=5.73, Pr >F=0.0078	A: (40000-80000), (Below 40000) B: (80000 above) **A>B***

* = **small sample size**

Tanker Events under Escort/No Escort

Escorts tugs can reduce the risk of accident occurrence for tankers. They can intercede in the event of power or steering failure, and can provide a power assist for tankers under power. However, a disadvantage of escort tugs is that additional vessels are introduced into the already congested waterway, increasing the potential for casualties between the escort tugs and other vessels. The analysis of tanker accidents and incidents under escort and not under escort can help in understanding the efficacy and quality of the escort system in the Puget Sound Marine transportation system. However, since transit data for vessels under escort and vessels not under no escort is not available, tests could only be run to determine whether there were significant differences of raw event frequencies in those two conditions, as seen in Table A-66. Since previous normalization analyses in this database have shown significant differences between raw data and normalized data trends, caution is advised with the escort vs. no escort analyses.

Table A-66 Tanker Events by Vessel under Escort/No Escort, 1995-2005

Escort or No Escort	Tanker Events		Accidents		Incidents	
	N	%	N	%	N	%
Escort	117	68.4	22*	62.9	82	73.9
No Escort	46	26.9	13*	37.1	28*	25.2
Null	8	4.7	2*	5.7	1*	0.9
Total	171	100	35*	100	111	100

*** = small sample size**

A Wilcoxon test of the Table A-66 data shows that tankers under escort had a higher number of total events and incidents than those with no escort. However, no difference of accident frequency was found for tankers under these two conditions (Table A-67). Therefore, the results may be different with normalized data, compared to the results with raw data. Note, however, that the accident statistics and the no-escort incident data are limited by small sample sizes.

Table A-67 Wilcoxon Tests of Tanker Events, Accidents, and Incidents by Vessels under Escort/no Escort, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Tanker Events	11	169.5000	2.8316	**0.0046**	**Escort> No Escort**
Accidents	11	143.5000	1.1590	0.2465	N/A
Incidents	11	167.5000	2.7099	**0.0067**	**Escort> No Escort***

*** = small sample size Bold results are statistically significant**

Tanker Events by Classification Society

Tanker events were characterized by the vessel's classification society, using information from Lloyd's List; the results from this analysis are shown in Table A-68.

Class Society	Tanker Events		Accidents		Incidents		Unusual Events	
	N	%	N	%	N	%	N	%
ABS	80	46.8	9*	25.7	59	53.2	12*	48
Lloyd's Register (LR)	6*	3.5	4*	11.4	2*	1.8	0	0
Nippon Kaiji Kyokai (NK)	5*	2.9	3*	8.6	1*	0.9	1*	4
Norske Veritas Classification A/S (NV)	3*	1.8	0	0	3*	2.7	0	0
Russian Maritime Register of Shipping (RS)	1*	0.6	0	0	1*	0.9	0	0
Null	76	44.4	19*	54.3	45	40.5	12*	48
Total	**171**	**100**	**35**	**100**	**111**	**100**	**25**	**100**

Table A-68 Tanker Events by Classification Society, 1995-2005

N: Number of records from the class society; %: Percent of records from the class society.

*** = Small sample size**

Table A-68 shows that ABS-classed vessels had the highest number of total events, accidents, incidents, and unusual events, compared to other class societies. However, statistical tests by class society are not available because of small sample sizes.

Tanker Accidents and Incidents by Event Type

In the Puget Sound VTRA Accident-Incident database, there were five types of tanker accidents: allisions, collisions, fire/explosion, groundings, and pollution. Tanker incidents were comprised of equipment failures, loss of power, loss of propulsion, loss of steering, near miss, and structural failure/damage. The statistical data are shown in Table A-69.

Table A-69 Puget Sound Tanker Accidents and Incidents by Type, 1995-2005

Accident Type	**Allision**	**Collision**	**Fire/ explosion**	**Grounding**		**Pollution**	
Frequency	4*	1*	2*	1*		27*	
Incident Type	**Equipment failure**	**Loss of power**	**Loss of propulsion**	**Loss of anchor**	**Loss of steering**	**Near miss**	**Structural failure /damage**
Frequency	55	1*	22*	3*	8*	4*	18*

*** = Small sample size**

Table A-69 shows that pollution was the major accident type and equipment failure was a major incident type for tankers in Puget Sound, 1995-2005. This pattern is consistent with that of all vessel types, as reported in the main body of this report. Kruskal-Wallis and Tukey's HSD analyses of the data also showed results similar to those for all vessels: that pollution is significantly the largest accident type, and equipment failures are the largest incident type (Table A-70). These results are all characterized by small sample sizes.

Table A-70 Kruskal-Wallis and Tukey's HSD tests of Tanker Accident and Incident types in Puget Sound, 1995-2005

Variable	DF	Test Statistics	Direction
Accident Type	4	Kruskal-Wallis: Chi-square statistic 29.4903, P>Chi-square <0.0001 Tukey's HSD: F-value= 16.56, Pr >F <0.0001	**Pollution* >Allision*, Fire*, Collision*, Grounding***
Incident Type	6	Kruskal-Wallis: Chi-square statistic 39.8337, P>Chi-square <0.0001 Tukey's HSD: F-value= 9.09, Pr >F <0.0001	**Equipment failure>Loss of Propulsion*, Structural Failure*, Loss of steering*, Near miss*, Loss of Anchor, Loss of Power***

*** = small sample size** **Bold results are statistically significant**

Tanker Events by Error Types

The frequency of tanker total events, accidents, and incidents caused by human and organizational error (HOE) and mechanical failure (MF) is shown in Table A-71.

Table A-71 Tanker Event Frequencies by Error Types, 1995-2005

Error	Total Event		Accident		Incident	
	N	%	N	%	N	%
HOE	41	24.0	15*	42.9	8*	7.2
MF	113	66.1	13*	37.1	100	90.1
Weather	5*	2.9	2*	5.7	3	2.7
Insufficient Information	12*	7.0	5*	14.3	0	0
Total	171	100	35*	100	111	100

*** = small sample size**

Earlier, Table A-37 showed Wilcoxon test results with tankers having significantly more events and incidents caused by mechanical failure than by human and organizational error; there was no statistically significant difference in tanker accidents caused by human error, compared to mechanical failure (Table A-72). With the exception of the event error types (which showed no significant error type results), these results are consistent with those shown for all vessels (Table A-37). However, these data are limited by small sample sizes.

Table A-72 Wilcoxon Tests of Tanker Events, Accidents, and Incidents by Error Type, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Tanker Events	11	77.5000	-3.2350	**0.0012**	**MF>HOE***
Accidents	11	127.5000	0.0698	**0.9443**	N/A
Incidents	11	75.0000	-3.4405	**0.0006**	**MF>HOE***

*** = small sample size**

Summary of Puget Sound Tanker Events, Accidents and Incidents, 1995-2005

Analysis of tanker events, accidents, and incidents showed that 2001 had the highest number of events and incidents, compared to other years. However, no statistical difference was found for accident frequencies from years 1995-2005. Tests on normalized data showed that 2002 had the highest number of accidents, compared to other years. When tanker events by season were analyzed, winter had the highest number of total events, accidents, and incidents, compared to other seasons. No statistically significant difference was found among the normalized data by season.

Analysis of tanker events by location showed that East and West Strait of Juan de Fuca had the highest number of total events and incidents, compared to other locations, and Cherry Point was found to have the highest number of accidents among locations. When analysis of data in the East and West Straits of Juan de Fuca was undertaken, for events before and after year 2000, Wilcoxon test results showed no statistically significant difference. These tanker results are significantly different than the results reported for all vessels, which showed South Puget Sound as the location with the highest number of events, accidents and incidents.

Analysis of tanker events by time of day showed that tankers had a statistically higher number of total events and incidents during the day than the night. In addition, U.S. flag, double hull, and Under Escort vessels had higher numbers of total events and incidents, compared to Non-U.S. flag, single hull, and No Escort vessels.

Analysis of tanker events by vessel size showed that small tankers (vessels below 40,000 DWT) had higher numbers of total events, accidents, and incidents, compared to vessels of other sizes.

For tankers, pollution was the major accident type and equipment failures were the major incident type, consistent with the results earlier reported for all vessel types. Analysis of tanker events by accident types showed that tanker pollution accidents occurred statistically more often than tanker accidents of other types. Similarly, analysis showed that tanker equipment failure incidents occurred significantly more often than tanker incidents of other types.

Analysis of tanker events by error type showed that tankers had higher number of total events and incidents caused by mechanical failure, rather than human error. These results were consistent with events by error type for all vessels in the Puget Sound VTRA Accident-Incident database.The significant test results of tanker vessels events data in Puget Sound are shown in Table A-72. Note that many of these data suffer from small sample sizes.

Test		Results	Test Used	Statistics	Direction
By Year	**Tanker Events**	**There are statistical differences in tanker events by year for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 24.1119, DF = 10, Pr > Chi-square =0.0073 F-value=3.62, DF = 10, Pr >F <0.0003	**A:2001 2002 2004 2003 1995** **B: 2002 2004 2003 1995 2000 1997 1999 1996 2005 1998** **A>B**
	Incidents	**There are statistical differences in tanker incidents by year for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 23.1115, DF = 10, Pr > Chi-square =0.0103 F-value=2.22, DF = 10, Pr >F =0.0207	**A: 2001 2004 2002 2000 1995 2003 1999 1996 1997 2005** **B: 2004 2002 2000 1995 2003 1999 1996 1997 2005 1998** **A>B**
By Year (normalized)	**Tanker Events**	**There are statistical differences in normalized tanker events for years 1996-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 23.9004, DF = 9, Pr > Chi-square =0.0045 F-value=3.69, DF = 9, Pr >F =0.0005	**A: 2002 2003 2005 1996 2004** **B: 2003 2005 1996 2004 1998 2001 1997 2000 1999** **A>B**
	Incidents	**There are statistical differences in normalized tanker incidents for year 1996-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 22.5624, DF = 9, Pr > Chi-square =0.0073 F-value=2.50, DF = 9, Pr >F =0.0120	**A: 2002 2003 1996 2005 2001 2004 1998 1997 2000** **B: 2003 1996 2005 2001 2004 1998 1997 2000 1999** **A>B**
By Location	**Tanker Events**	**There are statistical differences in tanker events by location for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 47.5930, DF = 9, Pr > Chi-square <0.0001 F-value=7.36, DF = 9, Pr >F <0.0001	**A: East Strait of Juan de Fuca, West Strait of Juan de Fuca B: West Strait of Juan de Fuca, Cherry point, Guemes Channel, South Puget Sound, Saddlebag C: Cherry point, Guemes Channel, South Puget Sound, Saddlebag, North Puget Sound, Rosario Strait, Haro Strait, San Juan Islands** A>B>C

Test		Results	Test Used	Statistics	Direction
	Accidents	**There are statistical differences in tanker accidents by location for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 22.4411, DF = 9, Pr > Chi-square =0.0076 F-value=2.65, DF = 9, Pr >F =0.0086	**A: Cherry Point, East Strait of Juan de Fuca, South Puget Sound, Guemes Channel, West Strait of Juan de Fuca, Rosario Strait, North Puget Sound, Haro Strait B: East Strait of Juan de Fuca, South Puget Sound, Guemes Channel, West Strait of Juan de Fuca, Rosario Strait, North Puget Sound, Haro Strait, Saddlebag, San Juan Islands** A>B
	Incidents	**There are statistical differences in tanker incidents by location among the 10 geographic areas for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 46.0565, DF = 9, Pr > Chi-square <0.0001 F-value=8.31, DF = 9, Pr >F <0.0001	**A: East Strait of Juan de Fuca, West Strait of Juan de Fuca B: West Strait of Juan de Fuca, Cherry point C: Cherry point, Guemes Channel, South Puget Sound, Saddlebag, Haro Strait, Rosario Strait, North Puget Sound, San Juan Islands** A>B>C
By Season	**Tanker Event**	**There are statistical differences in tanker events by season for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 24.8965, DF =3, Pr<0.0001 F-value=10.79, DF = 3, Pr >F =0.0001	**A: Winter Summer** **B: Summer Autumn** **C: Autumn Spring** **A>B>C**
	Accidents	**There are statistical differences in tanker accidents by season for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 9.6246, DF =3, Pr=0.0220 F-value=3.84, DF = 3, Pr >F =0.0166	**A: Winter Summer** **B: Summer Spring Autumn** **A>B**
	Incidents	**There are statistical differences in tanker incidents by season for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 18.9876, DF =3, Pr=0.0003 F-value=11.62, DF = 3, Pr >F <0.0001	**A: Winter** **B: Summer Spring Autumn** **A>B**
By Time of Day	**Tanker Events**	**Tanker events occurred more often during the day than the night for years 1995-2005**	Wilcoxon	Statistic 158.0000, Normal Approximation z= 2.1181, Pr> z=0.0342	**Day>Night**
	Incidents	**Tanker incidents occurred more often during the day than the night for years 1995-2005.**	Wilcoxon	Statistic 161.5000, Normal Approximation z= 2.3555, Pr> z=0.0185	**Day>Night**

Test		Results	Test Used	Statistics	Direction
By Flag (U.S. Flag vs. Non U.S. Flag)	**Tanker Events**	**U.S. flag tankers have higher event frequencies than tankers that are not U.S. flag for years 1995-2005.**	Wilcoxon	Statistic 178.5000, Normal Approximation z= 3.4243, Pr> z=0.0006	**US.>Non U.S.**
	Incidents	**U.S. flag tankers have higher incident frequencies than tankers that are not U.S. flag for years 1995-2005.**	Wilcoxon	Statistic 178.0000, Normal Approximation z= 3.4167, Pr> z=0.0006	**U.S.>Non U.S.**
By Vessel Size	**Tanker Events**	**Tankers > 80000 DWT and above had lower number of total event frequencies than tanker < 80000 DWT for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 13.2427, DF =2, P=0.0013 F-value=6.28, DF = 2, Pr >F =0.0053	**(Below 40000)= (40000-80000)> (80000 above)**
	Accidents	**Tankers with different deadweight tonnages had different accident frequencies for years 1995-2005**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 8.3235, DF =2, P=0.0156 F-value=4.66, DF =2, Pr >F =0.0173	**A: (Below 40000), (40000-80000)** **B: (40000-80000), (80000 above)** **A>B**
	Incidents	**Tankers with different deadweight tonnages had different incident frequencies for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 10.4913, DF =2, P=0.0053 F-value=5.73, DF =2, Pr >F=0.0078	**A: (40000-80000), (Below 40000)** **B: (80000 above)**
By Hull Type	**Tanker Events**	**Tankers with double hull has higher number of events frequency than tankers with single hull**	Wilcoxon	Statistic 91.0000, Normal Approximation z= -2.3390, Pr> z=0.0193	**Double Hull*>Single Hull***
	Accidents	**Tankers with double hull has higher number of accidents frequency than tankers with single hull**	Wilcoxon	Statistic 94.5000, Normal Approximation z= -2.2226, Pr> z=0.0262	**Double Hull*>Single Hull***
	Incidents	**Tankers with double hull has higher number of incidents frequency than tankers with single hull**	Wilcoxon	Statistic 93.0000, Normal Approximation z= -2.2206, Pr> z=0.0264	**Double Hull*>Single Hull***
By Escort vs. No Escort	**Tanker Events**	**Tankers under escort had higher number event frequencies than did tankers with no escort for years 1995-2005.**	Wilcoxon	Statistic 169.5000, Normal Approximation z= 2.8316, Pr> z=0.0046	**Escort> No Escort**
	Incidents	**Tankers under escort had higher incident frequencies than did tankers without escort for years 1995-2005.**	Wilcoxon	Statistic 167.5000, Normal Approximation z= 2.7099, Pr> z=0.0067	**Escort> No Escort**

Test		Results	Test Used	Statistics	Direction
By Accident/Incident Type	**Accidents**	**Tanker accidents caused by pollution had statistically higher frequencies than did other tanker accident types for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 29.4903, P>Chi-square <0.0001 F-value= 16.56, Pr >F <0.0001	**Pollution>Allision, Fire, Collision, Grounding**
	Incidents	**Tanker incidents caused by equipment failures had statistically higher frequencies than did other tanker incident types for years 1995-2005.**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 39.8337, P>Chi-square <0.0001 F-value= 9.09, Pr >F <0.0001	**Equipment failure>Loss of Propulsion, Structural Failure, Loss of steering, Near miss, Loss of Anchor, Loss of Power**
By Error Type (HOE vs. Mechanical)	**Tanker Events**	**Tankers had significantly more events caused by MF than by HOE for years 1995-2005.**	Wilcoxon	Statistic 77.5000, Normal Approximation z= -3.2350, Pr> z=0.0012	**MF>HOE**
	Incidents	**Tankers had significantly more incidents caused by MF than by HOE for years 1995-2005.**	Wilcoxon	Statistic 75.0000, Normal Approximation z= -3.4405, Pr> z=0.0006	**MF>HOE**

Table A-73: Summary of Significant Puget Sound Tanker Results for Events, Accidents and Incident Frequencies, 1995-2005

Appendix A-2
Puget Sound Tug-Barge Events, Accidents and Incident Analysis
1995-2005

Puget Sound Tug-Barge Events, Accidents, and Incidents, 1995-2005

In this section, an analysis of events occurring to tug-barges in the Puget Sound VTRA Accident-Incident database is analyzed. There were 421 events related to tug-barges in the accident-incident database; 325 (77.2%) were accidents, 87 (20.7%) were incidents, and 9 (2.1%) were unusual events (Table A-74). This compares to a smaller number of tanker events and accidents, and a higher number of tanker incidents, as seen in Table A-74. Statistical tests on tanker and tug-barge event data showed that tug-barges had a statistically higher number of total events and accidents than tankers when the raw data were analyzed; however, statistical tests on normalized data showed that tankers had a statistically higher number of total events and incidents than tug-barges; there were no statistically significant differences between tanker and tug-barge normalized accident frequencies over the period 1995-2005. Note that tanker accidents and unusual events, as well as tug-barge unusual events, are characterized by small sample sizes (Table A-75).

Table A-74 Puget Sound Tug-Barge Accidents, Incidents, and Unusual Events, 1995-2005

Event	Tug/barge	Percentage	Tankers	Percentage
Accidents	325	77.2%	35*	20.5%
Incidents	87	20.7%	111	64.9%
Unusual Events	9*	2.1%	25*	14.6%
Total	421	100%	171	100%

***=Small sample size**

Table A-75Wilcoxon Tests of Puget Sound Tug-Barge and Tanker Accidents and Incidents, 1995-2005

Variable		**N**	**Test statistic**	**Normal approximation Z**	**Two-sided Pr> $\lvert Z \rvert$**	**Directions**
Raw Data	**Total Events**	11	76.5000	-3.2842	0.0010	**Tug-Barge >Tanker***
	Accidents	11	67.0000	-3.9304	<0.0001	**Tug-Barge >Tanker***
	Incidents	11	149.5000	1.5146	0.1299	**N/A**
Normalized Data	**Total Events**	10	154.0000	3.7041	0.0002	**Tanker >Tug-Barge***
	Accidents	10	111.0000	0.4536	0.6501	**N/A**
	Incidents	10	145.0000	3.0237	0.0025	**Tanker >Tug-Barge***

* = **small sample size**

The accident:incident pyramids for tug-barges for each year between 1995-2005 are shown in Figure A-22. In contrast to the tanker accident-incident pyramids, which showed the greatest number of events in year 2001, year 2000 was the year with the greatest number of tug-barge events. Statistical tests on accident-incident ratios of both tankers and tug-barges show that tug-barges had a statistically higher accident-incident ratio than did tankers (Table A-76). Note, however, that these data suffer from small sample sizes.

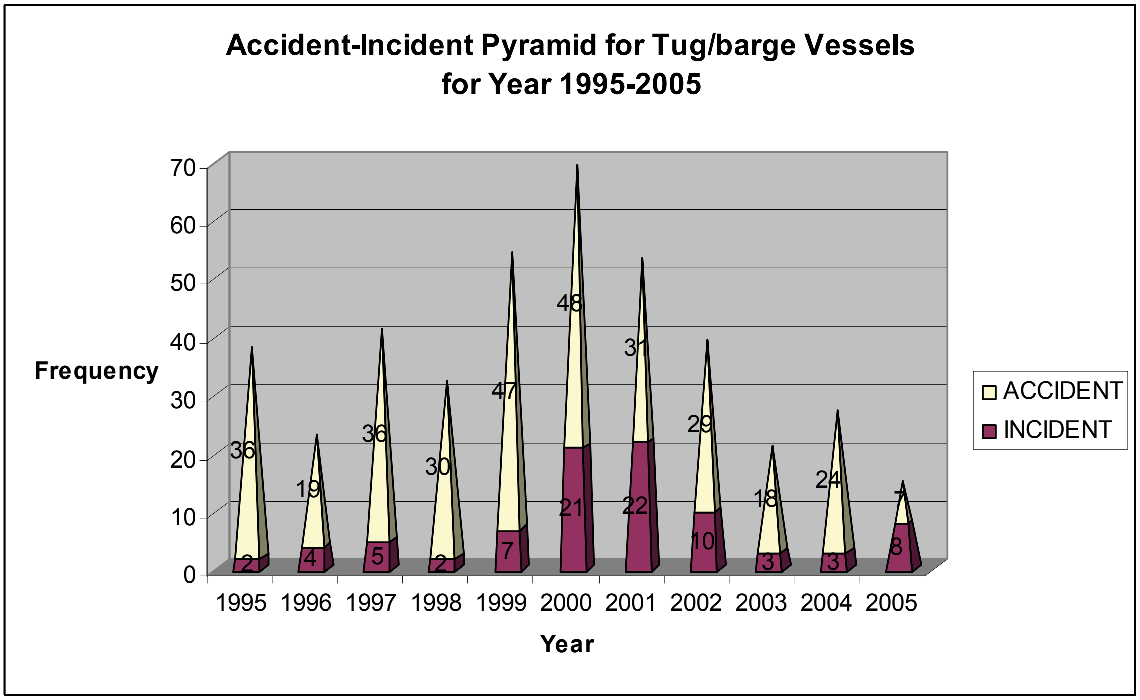


Figure A-22 Tug-Barge Accident-Incident Pyramids from year 1995-2005

Table A-76 Wilcoxon Tests on Accidents-Incidents Ratio for Both Tankers and Tug-Barges, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Ratio	11	77.0000	-3.2504	0.0012	**Tug-Barge >Tanker ***

*** = small sample size**

Tug-Barge Events by Location

Table A-77 and Figure A-23 show that total tug-barge events, accidents, incidents, and unusual events for different geographic locations for the years 1995-2005 occurred more often in South Puget Sound. In contrast to tanker events, which primarily occurred in the East and West Strait of Juan de Fuca, most tug-barge event occurred in South Puget Sound, as did tug-barge accidents, incidents, and unusual events. Note that the data in Table A-77 are limited by small sample sizes.

Table A-77 Tug-barge Total Events, Accidents, Incidents and Unusual Events by Location, 1995-2005

Zone	Total Tug-barge Events		Tug-barge Accidents		Tug-barge Incidents		Tug-barge Unusual Events	
	N	%	N	%	N	%	N	%
West Strait of Juan de Fuca	21*	5.0	8 *	2.5	13 *	14.9	0	0
East Strait of Juan de Fuca	23 *	5.5	13 *	4	10 *	11.5	0	0
North Puget Sound	39	9.3	28 *	8.6	11 *	12.6	0	0
South Puget Sound	254	60.3	226	69.5	25 *	28.7	3 *	33.3
Haro Strait/Boundary Pass	1 *	0.2	1 *	0.3	0	0	0	0
Rosario Strait	11 *	2.6	5 *	1.5	6 *	6.9	0	0
Guemes Channel	21 *	5.0	14 *	4.3	6 *	6.9	1 *	11.1
Saddlebag	17 *	4.0	14 *	4.3	3 *	3.4	0	0
Strait of Georgia/Cherry Point	20 *	4.8	8 *	2.5	11 *	12.6	1 *	11.1
San Juan Islands	4 *	1.0	3 *	0.9	1 *	1.1	0	0
Unknown	10 *	2.4	5 *	1.5	1 *	1.1	4 *	44.4
Total	**421**	**100**	**325**	**100**	**87**	**100**	**9 ***	**100**

N: Number of total events, accidents, incidents, unusual events;
%: Percent of event frequency for every zone. *** = small sample size**

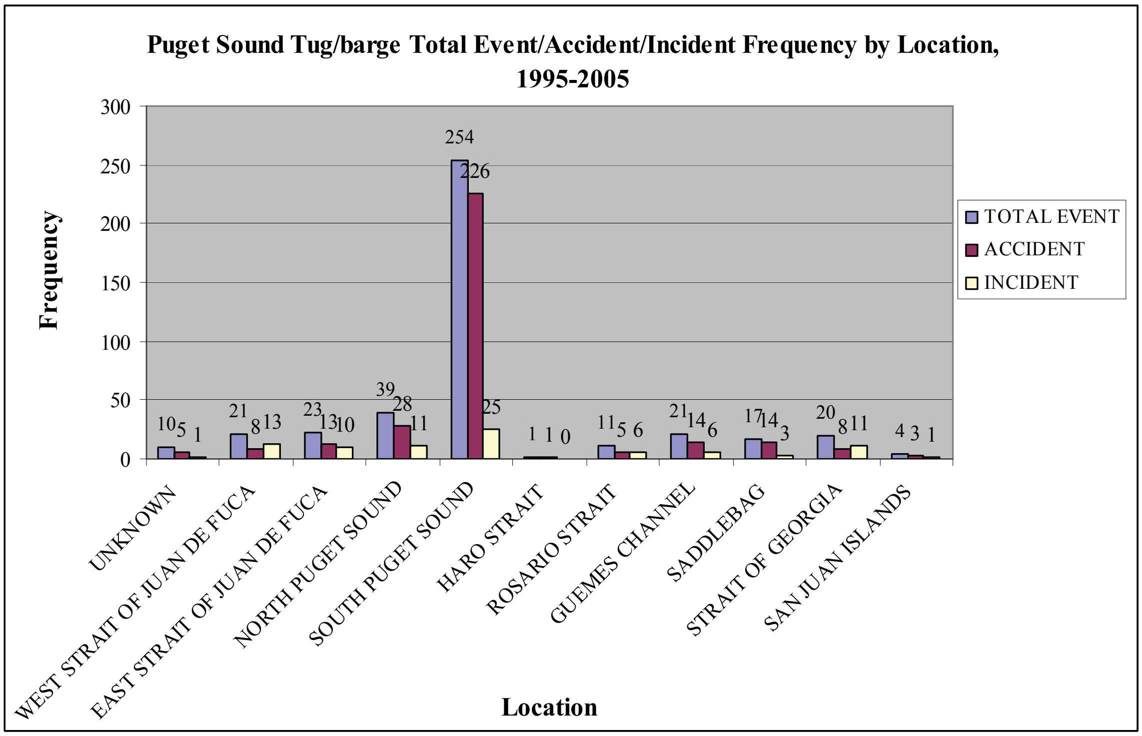


Figure A-23 Tug-Barge Accidents, Incidents and Unusual Events by Location

Analysis of Kruskal-Wallis and Tukey's HSD tests showed that there are statistical differences between total tug-barge events, accidents, incidents among the 10 zones, with South Puget Sound having more total tug-barge events and accidents frequencies than other remaining zones (Table A-78). Note that the distribution of significant locations for incidents is higher than those of events and accidents: in addition to South Puget Sound, incidents also occurred most frequently in the West Strait of Juan de Fuca, North Puget

Sound, Cherry Point, the East Strait of Juan de Fuca, Rosario Straits, and Guemes Channel. Normalization of the data by location was not possible since transit data corresponding to every zone was not available. Note, in addition, that the data is limited by small sample sizes.

Table A-78 Kruskal-Wallis and Tukey's HSD Tests on Tug-Barge Events, Accidents, and Incidents Frequencies by Location, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	9	Kruskal-Wallis: Chi-square statistic 56.0251, Pr > Chi-square <0.0001 Tukey's HSD: F-value=42.47, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, East Strait of Juan de Fuca, West Strait of Juan de Fuca, Guemes Channel, Cherry Point, Saddlebag, Rosario Strait, San Juan Islands, Haro Strait A>B ***
Accidents	9	Kruskal-Wallis: Chi-square statistic 51.3300, Pr > Chi-square <0.0001 Tukey's HSD: F-value=55.14, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, Guemes Channel, Saddlebag, East Strait of Juan de Fuca, West Strait of Juan de Fuca, Cherry Point, Rosario Strait, San Juan Islands, Haro Strait A>B ***
Incidents	9	Kruskal-Wallis: Chi-square statistic 21.6864, Pr > Chi-square =0.0099 Tukey's HSD: F-value=3.03, Pr >F =0.0030	**A: South Puget Sound, West Strait of Juan de Fuca, North Puget Sound, Cherry Point, East Strait of Juan de Fuca, Rosario Strait, Guemes Channel B: West Strait of Juan de Fuca, North Puget Sound, Cherry Point, East Strait of Juan de Fuca, Rosario Strait, Guemes Channel, Saddlebag, San Juan Islands, Haro Strait A>B ***

*** = small sample size**

Tug-Barge Events by Year

Tug-barge accidents, incidents, and unusual event frequencies from year 1995-2005 are shown in Figure A-24.

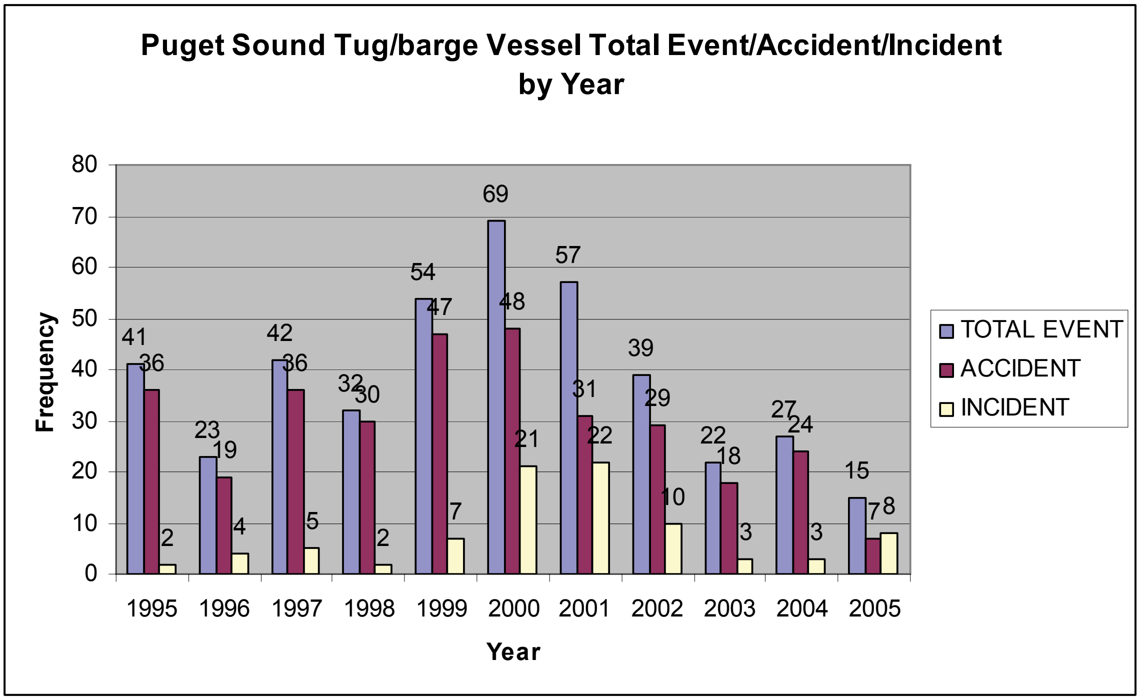


Figure A-24 Tug-Barge Accidents, Incidents and Unusual Events by Year, 1995-2005

Kruskal-Wallis and Tukey's HSD tests show that year 2000 had the highest number of events and accidents, while year 2001 had the highest number of incidents from 1995-2005. Tests on the normalized data showed that year 2001 had the highest number of normalized events and accidents, while year 2002 had the highest number of normalized incidents. These results are in contrast to the tanker results in the previous section, which showed that years 2001 and 2002 had significantly higher number of raw and normalized events, accidents, and incidents. Note that the results in Tables A-79 and A-80 are both limited by small sample sizes for accidents and incidents.

Table A-79 Puget Sound Tug-barge Normalized Events, Accidents and Incident Frequencies by Year, 1995 -2005 * = small sample size

Year (1)	Transit (2)		Total Event (3)		Normalized Event	Accident (5)		Normalized Accident	Incident (7)		Normalized Incident	Unusual Event (9)	
	N	%	N	%	(4)=(3)/(2)	N	%	(6)=(5)/(2)	N	%	(8)=(7)/(2)	N	%
1995	N/A	N/A	41	9.74	N/A	36 *	11.708	N/A	2 *	2.30	N/A	3*	33.3
1996	24477	9.4	23	5.46	0.00094	19*	5.85	0.000776	4 *	4.60	0.000163	0*	0
1997	30969	11.9	42	9.98	0.001356	36*	11.08	0.001162	5*	5.75	0.000161	1*	11.1
1998	25769	9.9	32*	7.60	0.001242	30*	9.23	0.001164	2*	2.30	0.0000776	0*	0
1999	27016	10.4	54	12.83	0.001999	47	14.46	0.00174	7*	8.05	0.000259	0*	0
2000	27553	10.6	69	16.39	0.002504	48	14.77	0.001742	21*	24.14	0.000762	0*	0
2001	24941	9.6	57	13.54	0.002285	31*	9.54	0.001243	22*	25.29	0.000882	4*	44.4
2002	24776	9.5	39	9.26	0.001574	29*	8.92	0.00117	10*	11.49	0.000404	0*	0
2003	26342	10.1	22*	5.23	0.000835	18*	5.54	0.00683	3*	3.45	0.000114	1*	11.1
2004	24456	9.4	27*	6.41	0.001104	24*	7.38	0.000981	3*	3.45	0.000123	0*	0
2005	24139	9.3	15*	3.56	0.000621	7*	2.15	0.00029	8*	9.20	0.000331	0*	0
Total	260438	100	421	100	N/A	325	100	N/A	87	100	N/A	9*	100

Table A-80 Kruskal-Wallis and Tukey's HSD Test Statistics of Raw and Normalized Tug-Barge Total Events, Accidents, and Incidents, 1995-2005

Variable		Test Statistics	Direction
Raw Data	**Total Events**	Kruskal-Wallis: Chi-square statistic 45.2864, DF = 10, Pr > Chi-square <0.0001 Tukey's HSD: F-value=6.72, DF = 10, Pr >F <0.0001	**A:2000 2001 1999 1997 1995 B: 2001 1999 1997 1995 2002 1998 C: 1999 1997 1995 2002 1998 2004 D: 1997 1995 2002 1998 2004 1996 2003 2005 A>B>C>D**
	Accidents	Kruskal-Wallis: Chi-square statistic 39.4093, DF = 10, Pr > Chi-square <0.0001 Tukey's HSD: F-value=5.12, DF = 10, Pr >F <0.0001	**A: 2000 1999 1997 1995 2001 1998 2002 2004 B: 1997 1995 2001 1998 2002 2004 1996 2003 C: 2001 1998 2002 2004 1996 2003 2005 A>B>C ***
	Incidents	Kruskal-Wallis: Chi-square statistic 49.9608, DF = 10, Pr > Chi-square <0.0001 Tukey's HSD: F-value=8.33, DF = 10, Pr >F <0.0001	**A: 2001 2000 B: 2000 2002 C: 2002 2005 1999 1997 1996 2004 2003 1998 1995***
Normalized Data	**Total Events**	Kruskal-Wallis: Chi-square statistic 36.2490, DF = 9, Pr > Chi-square <0.0001 Tukey's HSD: F-value=5.81, DF = 9, Pr >F <0.0001	**A: 2001 2002 2000 1996 B: 2002 2000 1996 1998 2003 1999 C: 2000 1996 1998 2003 1999 2005 2004 1997 A>B>C**
	Accidents	Kruskal-Wallis: Chi-square statistic 25.6630, DF = 9, Pr > Chi-square =0.0023 Tukey's HSD: F-value=3.36, DF = 9, Pr >F =0.0011	**A: 2001 2000 1996 1998 2002 2003 1999 B: 2000 1996 1998 2002 2003 1999 2005 2004 1997 A>B**
	Incidents	Kruskal-Wallis: Chi-square statistic 49.3806, DF = 9, Pr > Chi-square <0.0001 Tukey's HSD: F-value=9.74, DF = 9, Pr >F <0.0001	**A: 2002 2001 B: 2003 2000 1998 2005 1997 2004 1996 1999 A>B**

* = small sample size

There was also no difference in tug-barge total events, accidents, or incidents before and after the year 2000, using the Wilcoxon test.

Tug-Barge Events by Season

The raw and normalized total events, accidents, and incidents frequencies for tug-barges by season are shown in Figures A-25 and A-26.

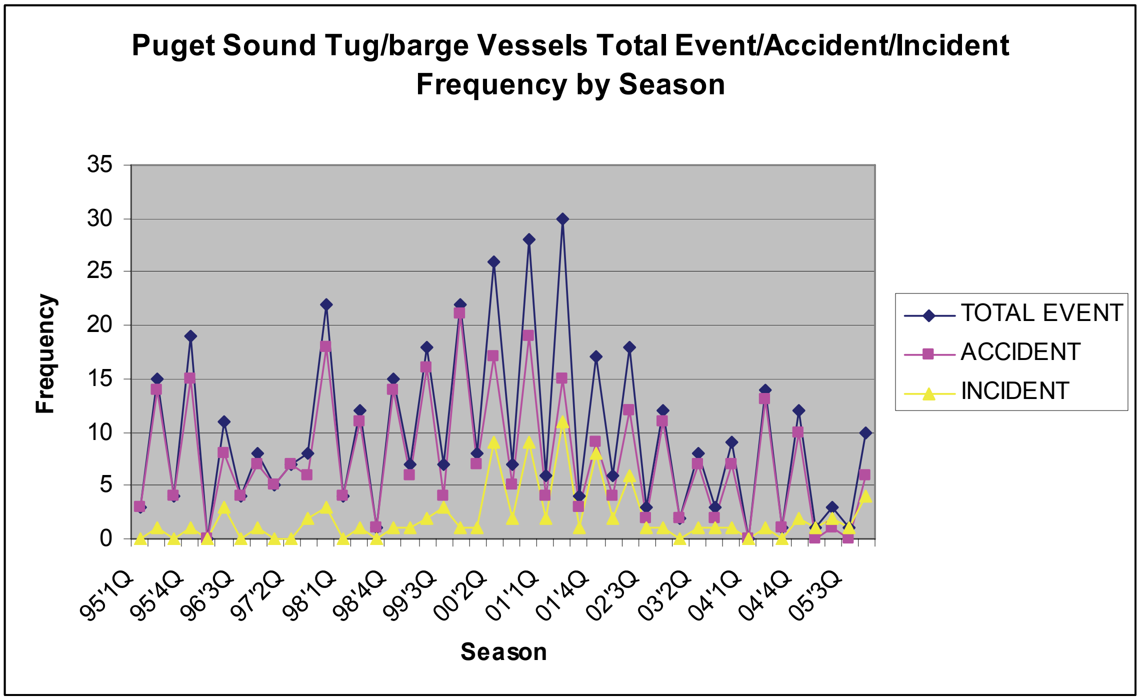


Figure A-25 Raw Tug-Barge Total Events, Accidents, and Incidents by Season, 1995-2005

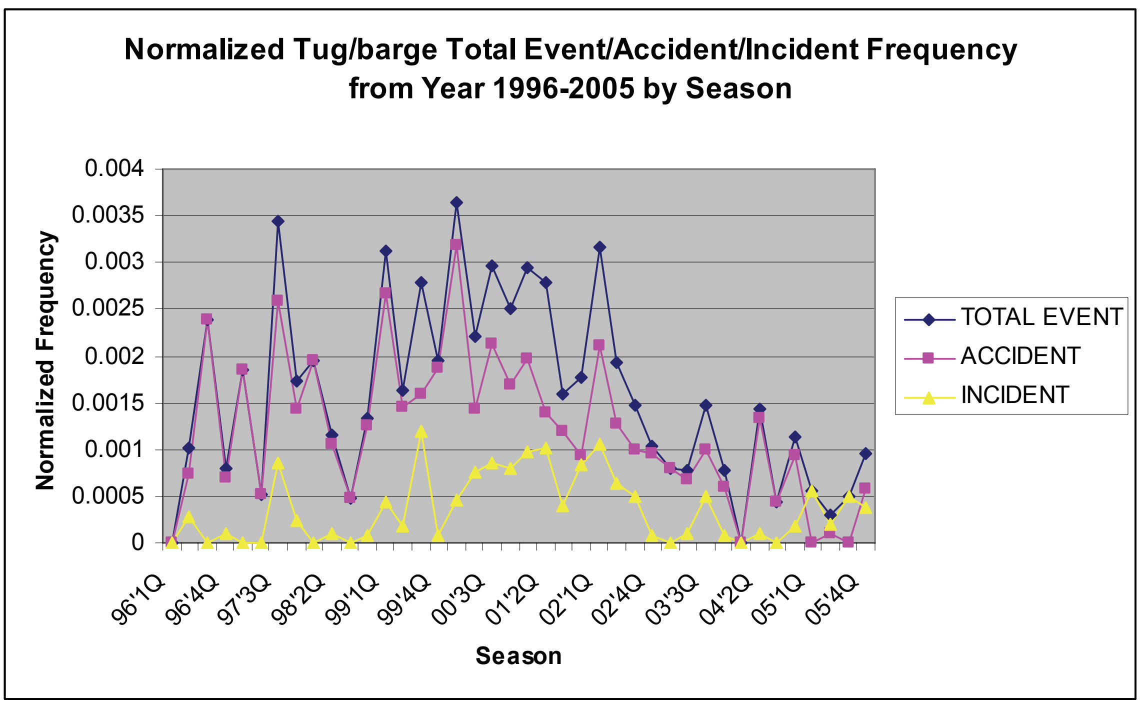


Figure A-26 Normalized Tug-Barge Total Events, Accidents, and Incidents by Season, 1996-2005

Kruskal-Wallis and Tukey's HSD tests on the raw data showed that winter and summer had a higher number of tug-barge total events and accidents than did autumn and spring, with no difference of incident frequency among the four seasons. However, the same tests on the normalized data found no differences in total events, accidents, and incidents among the four seasons for tug-barges (Table A-81). For raw data, winter and summer had the highest number of tug-barge total events and accidents, compared to spring and autumn, the same results as those of tanker ships (Table A-51). However, tug-barges did not have a statistically different number of incidents among the four seasons as tank ships did. Both tug-barges and tank ships did not have statistically different number of normalized total events, accidents, and incidents.

Table A-81 Kruskal-Wallis and Tukey's HSD tests of Raw and Normalized Tug-Barge Events, Accidents and Incidents by Season

Variable		DF	Test statistic	Direction
Raw Data	Total Events	3	Kruskal-Wallis: Chi-square statistic 27.8035, DF =3, Pr<0.0001 Tukey's HSD: F-value=16.03, DF = 3, Pr >F <0.0001	**A: Winter Summer B: Autumn Spring A>B ***
	Accidents	3	Kruskal-Wallis: Chi-square statistic 27.2958, DF =3, Pr<0.0001 Tukey's HSD: F-value=18.59, DF = 3, Pr >F <0.0001	**A: Winter Summer B: Spring Autumn A>B ***
	Incidents	3	Kruskal-Wallis: Chi-square statistic 10.6972, DF =3, Pr=0.0135 Tukey's HSD: F-value=3.42, DF = 3, Pr >F =0.0263	N/A
Normalized	Total Events	3	Chi-square statistic 1.0085, DF =3, P=0.7992 Tukey's HSD: F-value=0.50, DF = 3, Pr >F =0.6816	N/A
	Accidents	3	Chi-square statistic 1.1584, DF =3, P=0.7630 Tukey's HSD: F-value=0.63, DF = 3, Pr >F =0.6017	N/A
	Incidents	3	Chi-square statistic 1.1753, DF =3, P=0.7589 Tukey's HSD: F-value=0.48, DF = 3, Pr >F =0.6965	N/A

*** = small sample size**

A seasonality index was also constructed to assess the likelihood of tug-barge events, accidents and incidents in Puget Sound by season between 1995 and 2005. This analysis showed that events in summer and winter seasons occurred more often than in the spring and autumn seasons due to the longer periods; for normalized events, spring and autumn had more events, accidents, and incidents than other seasons (Table A-82); The normalized tug-barge results differ from raw tug-barge results: using a normalized seasonality index, spring and autumn had the most tug-barge events, accidents, and incidents; these results were contrary to the tanker seasonality index results, both raw and normalized (Table 52), which showed normalized tanker events occurring most frequently in winter, normalized tanker accidents occurring in summer and winter, and normalized tanker incidents occurring most frequently in spring and winter. Note that these data are limited by small sample sizes.

Table A-82 Raw and Normalized Seasonal Index for Tug-Barge Events, Accidents, and Incidents, 1995-2005

Season	Raw Seasonal Index		
	Total Event	Accident	Incident
Spring	0.40 (0.28)	0.43 (0.23)	0.32 (0.36)
Summer	1.54 (1.29)	1.49 (1.49)	1.70 (1.15)
Autumn	0.41 (0.33)	0.39 (0.23)	0.51 (0.29)
Winter	1.65 (2.11)	1.69 (2.06)	1.47 (2.20)
	Normalized Seasonal Index		
Spring	1.14 (0.81)	1.20 (0.49)	0.96 (1.10)
Summer	0.87 (0.82)	0.83 (1.06)	0.93 (0.82)
Autumn	1.11(0.98)	1.06 (0.91)	1.32 (0.88)
Winter	0.88 (1.39)	0.91 (1.54)	0.80 (1.38)

Note: The number in ( ) is the corresponding value of tugs

Tug-Barge Events by Time of Day

Events that occurred in the Puget Sound VTRA area between 1995 and 2005 occurred during the day or night. The data of occurrence times are shown in Table A-83.

Table A-83 Tug-barge Events, Accidents, and Incidents by Time of Day, 1995-2005

Time of Day	Total Event		Accident		Incident	
	N	%	N	%	N	%
Day	200	47.5	158	48.6	39*	44.8
Night	92	21.9	73	22.5	18*	20.7
Null	129	30.6	94	28.9	30*	34.5
Total	421	100	325	100	87	100

N = Number or Frequency; %: Percent of Frequency;

***=Small sample size**

From the table, it can be seen that many of the tug-barge events, accidents, and incidents occurred during the day, probably because there are more vessel transits during the day than night. However, note that almost half of the tug-barge records do not have timing information associated with the event. A Wilcoxon test on the raw data showed no statistical differences in total events, accidents, and incidents between day and night. These results differ from the tanker results in the previous section, which found that tanker events and incidents occurred significantly more often in the day rather than the night. The tanker data was similarly characterized by large amounts of missing timing information.

Table A-84 Wilcoxon Tests on Tug-Barge Events, Accidents, and Incidents by Vessel Time of Day, 1995-2005

Variable	N	Test statistic	Normal approximate Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	11	145.5000	1.2530	0.2102	N/A
Accidents	11	142.5000	1.0575	0.2903	N/A
Incidents	11	134.0000	0.5047	0.6137	N/A

Tug-Barge Events by Vessel Flag

Tug-barge events that occurred in the Puget Sound VTRA area of interest between 1995 and 2005 occurred aboard tug-barges of varying flags, as seen in Figure A-27. More events occurred to U.S. flag tug-barges during the reporting period than to non-U.S. flag tug-barges; these differences were significant at the 95% confidence level using the Wilcoxon test. Similarly, significantly more accidents (349, 82.9%) occurred to U.S. flag tug-barges than to non-U.S. flag tug-barges; these differences were found to be significant at the 95% level, using the Wilcoxon test (Table A-85). A similar pattern was observed in total numbers of incidents over the time period, with 87.4% of the incidents occurring to U.S. tug-barges. These differences were found to be significant at the 95% level using the Wilcoxon test.

These results, with the exception of the accident results, are consistent with the tanker results in the previous section. Tanker accidents showed no significant effect for vessel flag (Table A-56). Note that the foreign flag tanker events, accidents and incidents comprise between 20-40% of each event type; in contrast, the tug-barge events, accidents and incidents are almost completely (85-90%) dominated by U.S. flag tug-barges. This is perhaps because of the very small number of foreign flag tug-barges operating in Puget Sound during the reporting period.

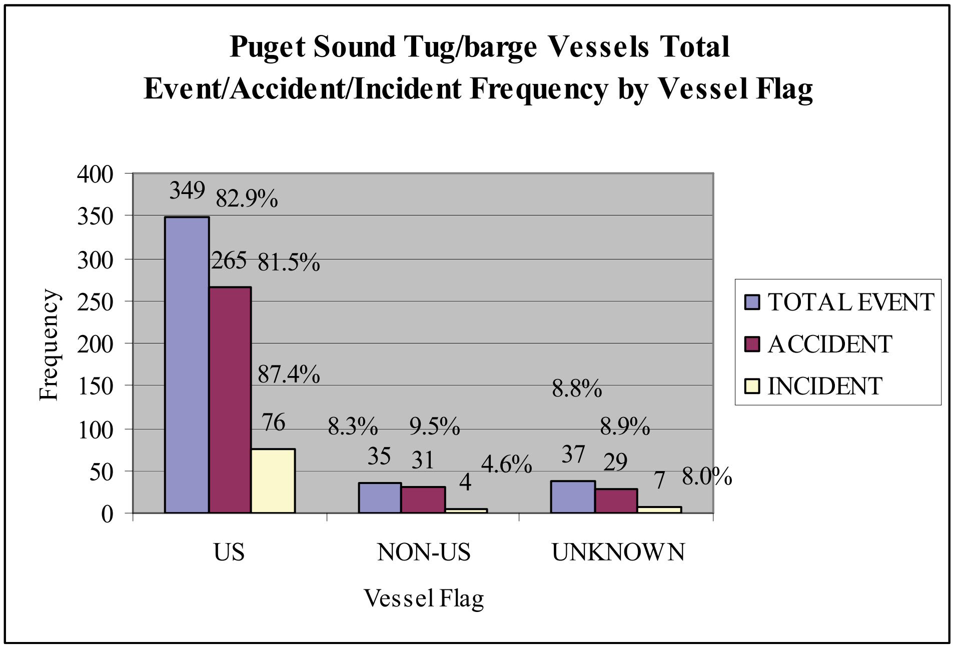


Figure A-27 Tug-Barge Events by Vessel Flag, 1995-2005

Table A-85 Wilcoxon Tests on Tug-Barge Events, Accidents, and Incidents by Vessel Flag, 1995-2005

Variable	N	Test statistic	Normal Approximation Z	Two-sided Pr> $\|Z\|$	Direction
Total Events	11	187.0000	3.9874	<0.0001	**U.S.>Non U.S. ***
Accidents	11	185.0000	3.8822	0.0001	**U.S.>Non U.S. ***
Incidents	11	185.5000	3.9837	<0.0001	**U.S.>Non U.S. ***

* = **small sample size**

Total tug-barge events, accidents, and incidents for foreign flag tug-barge vessels are shown in Table A-86.

Table A-86 Puget Sound Foreign Flag Tug-barge Events, Accidents, and Incidents by Flag, 1995-2005

Vessel Flag	Total Event		Accident		Incident	
	N	%	N	%	N	%
US	349	82.9	265	81.5	76	87.4
BRAZIL	2*	0.5	2*	0.6	0	0
CANADA	27*	6.4	23*	7.1	4*	4.6
NIGERIA	1*	0.2	1*	0.3	0	0
PANAMA	2*	0.5	2*	0.6	0	0
VANUATU	1*	0.2	1*	0.3	0	0
OTHER	39	9.3	31	9.5	7*	8.0
TOTAL	**421**	**100**	**325**	**100**	**87**	**100**

***=Small sample size**

Table A-86 shows that Canadian tug-barges have the highest frequency of events, accidents and incidents, compared to other foreign flag tug-barges in Puget Sound. However, with the exception of the U.S. flag data, all tug-barge foreign flag data is limited by small sample sizes.

Tug-Barge Events by Vessel Owner

There are significant differences in tug-barge events among different tug-barge owners. However, some vessel owners may no longer exist, or some vessels may have changed their operators.

Table A-87 Tug-barge Events, Accidents, Incidents and Unusual Events by Vessel Owner, 1995-2005

Vessel Owner	Total Event		Accident		Incident		Unusual Event	
	N	%	N	%	N	%	N	%
Foss	68	16.2	54	16.6	10*	11.5	4*	44.4
Sause Brothers Ocean Towing Co. Inc.	6*	1.4	4*	1.2	2*	2.3	0	0
Island Tug & Barge Co.	24*	5.7	19*	5.8	5*	5.7	0	0
Sea Coast Transportation LLC	8*	1.9	4*	1.2	4*	4.6	0	0
Marine Transport Corp.	6*	1.4	2*	0.6	4*	4.6	1*	11.1
Seaspan International Ltd.	12*	2.9	12*	3.7	0	0	0	0
U.S. Shipping Partners LP	7*	1.7	1*	0.3	6*	6.9	1*	11.1
U.S. Navy	15*	3.6	15*	4.6	0	0	0	0
Western Towboat Company	6*	1.4	6*	1.8	0	0	0	0
Olympic Tug & Barge Inc.	30*	7.1	23*	7.1	7*	8.0	0	0
Dunlap Towing Company	7*	1.7	4*	1.2	3*	3.4	0	0
Crowley	54	12.8	44	13.5	10*	11.5	0	0
Other	178	42.3	127	39.1	36*	41.4	3*	33.3
TOTAL	**421**	**100**	**325**	**100**	**87**	**100**	**9***	**100**

***=Small sample size**

Table A-87 shows Foss, Crowley, Olympic Tug & Barge, and Island Tug & Barge Co. are the tug-barge vessel owners with the highest event and accident frequencies. A Kruskal-Wallis test shows that tug-barges from these four owners had no statistical difference in terms of incident frequencies (Table A-88). Normalized results for this analysis may have shown different results than the raw data results shown in Table A-88.

Table A-88 Kruskal-Wallis and Tukey's HSD Tests on Tug-Barge Events, Accidents, and Incidents by Vessel Owner, 1995-2005

Variable	DF	Test Statistics	Direction
Total Events	3	Kruskal-Wallis: Chi-square statistic 10.7222, P> Chi-square =0.0145 Tukey's HSD: F-value=4.69, Pr >F =0.0090	A: Foss; Crowley; Olympic Tug & Barge Inc. B: Crowley; Olympic Tug & Barge; Island Tug & Barge Co **A>B ***
Accidents	3	Kruskal-Wallis: Chi-square statistic 11.0232, P> Chi-square =0.0178 Tukey's HSD: F-value=4.56, Pr >F =0.0098	A: Foss; Crowley; Olympic Tug & Barge B: Crowley; Olympic Tug & Barge; Island Tug & Barge Co **A>B***
Incidents	3	Kruskal-Wallis: Chi-square statistic 1.9896, P> Chi-square =0.5922	N/A

*** = small sample size**

Tug-Barge Events by Classification Society

The information about the class society for tug-barges can be found in Table A-89.

Table A-89 Tug-Barge Events, Accidents, Incidents and Unusual Events by Class Society, 1995-2005

Class Society	Total Event		Accident		Incident		Unusual Event	
	N	%	N	%	N	%	N	%
ABS	113	26.8	80	24.6	30 *	34.5	3 *	33.3
Bureau Veritas (BV)	1 *	0.2	0	0	1 *	1.1	0	0
Lloyd's Register (LR)	4 *	1.0	3 *	0.9	1 *	1.1	0	0
Registro Italiano Navale (RINA) (RI)	1 *	0.2	1 *	0.3	0	0	0	0
Null	302	71.7	241	74.2	55	63.2	6 *	66.6
Total	**421**	**100**	**325**	**100**	**87**	**100**	**9 ***	**100**

*** = small sample size**

From Table A-89, we can find that ABS class tug-barges had the highest number of total events, accidents, incidents, and unusual events than other class societies. Statistical tests on tug-barge event data are not available because of small sample sizes.

Tug-Barge Events by Hull Type

There are four hull types for tug-barges in the database: single hull, double hull, double sides, and double bottoms. Table A-90 shows the numbers of tugs with different hull types. Note in Table A-90 that some records were missing information about hull type and thus were classified as "unknown". A Wilcoxon test of the Table A-90 tug-barge data shows that single hull tug-barges had a higher number of total events, accidents, and incidents than double hull tug-barges (Table A-91). These results contrast with the tanker results, which showed that double-hulled tankers had significantly higher numbers of events, accidents and incidents over the reporting period. This may be because of the dominance of double-hulled tankers in the tanker data records, and the dominance of single hull tug-barges in the tug-barge data records. Transit data was not available to normalize the data. Given the differences that were observed with this data set when the data were normalized, as analysis of the differences in event frequencies by hull type for both raw and normalized data should be undertaken.

Table A-90 Tug-Barge Accidents, Incidents, and Unusual Events by Hull Type, 1995-2005

Event	Single Hull	Double Hull	Unknown
Accidents	274	1*	50
Incidents	71	6*	10*
Unusual Events	6*	1*	2*
Total	**351**	**8***	**62**

*** = small sample size**

Table A-91 Wilcoxon Tests on Tug-Barge Events, Accidents, and Incidents Frequencies by Hull Type 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	11	187.0000	4.0172	<0.0001	**Single hull > Double hull***
Accidents	11	187.0000	4.1158	<0.0001	**Single hull > Double hull***
Incidents	11	185.0000	3.9220	<0.0001	**Single hull > Double hull***

*** = small sample size**

Tug-Barge Accidents and Incidents by Event Type

In the Puget Sound Accident-Incident database, there are five types of tug-barge accidents: allisions, collisions, fire/explosions, groundings, and pollution. Tug-barge incidents were comprised of equipment failures, loss of power, loss of propulsion, loss of steering, near misses, and structural failure/damage. The statistical data are shown in Tables A-92 and A-93.

Table A-92 Puget Sound Tug-Barge Accident Frequency by Accident Type, 1995-2005

Accident Type	Allision	Breakaway	Capsize	Collision	Fire/explosion
Frequency	90	4*	7*	20*	7*
Accident Type	**Flooding**	**Grounding**	**Pollution**	**Salvage**	**Sinking**
Frequency	5*	22*	164	0	6*

*** = small sample size**

Table A-93 Puget Sound Tug-Barge Incident Frequency by Incident Type, 1995-2005

Incident Type	Equipment Failure	Loss of power	Loss of propulsion	Loss of steering	Near miss	Structural failure/damage
Frequency	55	0	17*	6*	5*	4*

***=Small sample size**

Tables A-92 and A-93 show that pollution was again the major accident type and equipment failure was the major incident type for tug-barges in Puget Sound between 1995-2005, as confirmed by Kruskal-Wallis and Tukey's HSD tests (Table A-94). These results are identical to those shown for all vessels (Tables A-33 and A-34); however, the results are limited by a small sample size.

Table A-94 Kruskal-Wallis and Tukey's HSD tests results on Tug-Barge Accidents and Incidents by Event Type, 1995-2005

Variable	DF	Test Statistics	Direction
Accident Type	8	Kruskal-Wallis: Chi-square statistic 52.8120, P>Chi-square <0.0001 Tukey's HSD: F-value= 29.29, Pr >F <0.0001	**Pollution>Allision>Grounding, Collision, Fire, Capsize, Sinking, Flooding, Breakaway***
Incident Type	4	Kruskal-Wallis: Chi-square statistic 17.8887, P>Chi-square =0.0013 Tukey's HSD: F-value= 7.76, Pr >F <0.0001	**Equipment failure>Loss of Propulsion, Loss of steering, Near miss, Structural Failure ***

*** = small sample size**

Tug-Barge Events by Error Type

The frequency of tug-barge total events, accidents, and incidents caused by human error and mechanical failure are shown in Table A-95.

Table A-95 Tug-Barge Accidents and Incidents by Error Type, 1995-2005

Year	Tug/barge accident	Tug/barge accident by HOE	Tug/barge accident by MF	Tug/barge incident	Tug/barge incident by HOE	Tug/barge incident by MF
1995	36 *	0	0	2 *	0	2 *
1996	19 *	2*	1 *	4 *	0	4 *
1997	36 *	7 *	2*	5 *	0	4 *
1998	30 *	4 *	1*	2 *	0	2 *
1999	47	4*	0*	7 *	0	7 *
2000	48	4*	2*	21*	0	21*
2001	31 *	4*	0	22 *	1 *	21 *
2002	29 *	0	0	10 *	0	9 *
2003	18 *	2*	0	3 *	2 *	1*
2004	24 *	0	2*	3 *	0	3 *
2005	7 *	2*	1*	8 *	0	8 *

Wilcoxon tests show that, for tug-barges, more total events and accidents are caused by human error than are caused by mechanical failures. However, more incidents are caused by mechanical failure, rather than human error (Table A-96). These results are consistent with those shown for all vessels (Table A-36). The tug-barge results are identical to the tanker results, with the exception of accidents, which showed no significant trend in the tanker data (Table A-72). Note, however, that the data are limited by small sample sizes.

Table A-96 Wilcoxon Tests on Tug-Barge Events, Accidents, and Incidents Frequencies by Error Type, 1995-2005

Variable	N	Test statistic	Normal approximation Z	Two-sided Pr> $\lvert Z \rvert$	Direction
Total Events	11	94.5000	-2.1139	0.0345	**MF>HOE***
Accidents	11	157.0000	2.0825	0.0373	**HOE>MF***
Incidents	11	68.5000	-3.9529	<0.0001	**MF>HOE***

Summary of Tug-Barge Events, Accidents and Incidents, 1995-2005

Test results of tug-barge total events, accidents, and incidents by year showed that year 2000 had the highest event and accident frequencies while year 2001 had the highest incident frequencies between 1995-2005. Tests on the normalized data showed that year 2001 had the highest normalized event and accident frequencies while year 2002 had the highest normalized incident frequency.

Test results of tug-barge events by season showed that winter and summer had a statistically higher number of total events and accidents than did spring and autumn. However, no statistical difference in accidents was found among the four seasons. Furthermore, tests on the normalized tug-barge data showed no statistical difference in total events, accidents, and incidents.

Tests on tug-barge total events, accidents, and incidents by location showed that South Puget Sound had a significantly higher number of total events, accidents and incidents, compared to other locations. This result is in contrast to the tanker events, which occurred significantly more frequently in the East and West Straits of Juan de Fuca.

Significant test results showed that U.S. flag tug-barges had significantly more events, accidents, and incidents frequencies than non-U.S. flag tug-barges. Tests on tug-barge data by hull type showed that single hull tug-barges had a statistically higher number of total events, accidents, and incidents than double hull tug/barges.

For tug-barges, as with the tankers, pollution was the major accident type, and equipment failures were the most frequent incident type in Puget Sound between 1995 and 2005. Tests on tug-barge data by error type showed that tug-barges had statistically higher number of total events and accidents caused by human error than those by mechanical failure. However, tug-barges had significantly more incidents caused by mechanical failure than those by human error. These results were consistent with those results for all vessels. The significant test results of tug-barge total events, accidents, incidents are shown in Table A-97. Note, however, that many of these results are limited by small sample sizes.

Table A-97 Summary of Significant Puget Sound Tug-Barge Event, Accident and Incident Results, 1995-2005

Test		Results	Test Used	Statistics	Direction
by Year	**Total Events**	**There are statistics differences of total event from year 1995-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 45.2864, DF = 10, Pr > Chi-square <0.0001 F-value=6.72, DF = 10, Pr >F <0.0001	**A:2000 2001 1999 1997 1995 B: 2001 1999 1997 1995 2002 1998 C: 1999 1997 1995 2002 1998 2004 D: 1997 1995 2002 1998 2004 1996 2003 2005 A>B>C>D**
	Accidents	**There are statistics differences of accident from year 1995-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 39.4093, DF = 10, Pr > Chi-square <0.0001 F-value=5.12, DF = 10, Pr >F <0.0001	**A: 2000 1999 1997 1995 2001 1998 2002 2004 B: 1997 1995 2001 1998 2002 2004 1996 2003 C: 2001 1998 2002 2004 1996 2003 2005 A>B>C ***
	Incidents	**There are statistics differences of incident from year 1995-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 49.9608, DF = 10, Pr > Chi-square <0.0001 F-value=8.33, DF = 10, Pr >F <0.0001	**A: 2001 2000 B: 2000 2002 C: 2002 2005 1999 1997 1996 2004 2003 1998 1995***
By Year (normalized)	**Total Events**	**There are statistics differences of normalized total events from year 1996-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 36.2490, DF = 9, Pr > Chi-square <0.0001 F-value=5.81, DF = 9, Pr >F <0.0001	**A: 2001 2002 2000 1996 B: 2002 2000 1996 1998 2003 1999 C: 2000 1996 1998 2003 1999 2005 2004 1997 A>B>C**
	Accidents	**There are statistics differences of normalized accidents from year 1996-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 25.6630, DF = 9, Pr > Chi-square =0.0023 F-value=3.36, DF = 9, Pr >F =0.0011	**A: 2001 2000 1996 1998 2002 2003 1999 B: 2000 1996 1998 2002 2003 1999 2005 2004 1997 A>B**
	Incidents	**There are statistics differences of normalized incidents from year 1996-2005 for tug/barge vessels**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 49.3806, DF = 9, Pr > Chi-square <0.0001 F-value=9.74, DF = 9, Pr >F <0.0001	**A: 2002 2001 B: 2003 2000 1998 2005 1997 2004 1996 1999 A>B**
by Location	**Total Events**	**South Puget Sound had more tug/barge total event frequency than other areas**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 56.0251, DF = 9, Pr > Chi-square <0.0001 F-value=42.47, DF = 9, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, East Strait of Juan de Fuca, West Strait of Juan de Fuca, Guemes Channel, Cherry Point, Saddlebag, Rosario Strait, San Juan Islands, Haro Strait A>B ***

Test		Results	Test Used	Statistics	Direction
	Accidents	**South Puget Sound had more tug/barge accident frequency than other areas**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 51.3300, DF = 9, Pr > Chi-square <0.0001 F-value=55.14, DF = 9, Pr >F <0.0001	**A: South Puget Sound B: North Puget Sound, Guemes Channel, Saddlebag, East Strait of Juan de Fuca, West Strait of Juan de Fuca, Cherry Point, Rosario Strait, San Juan Islands, Haro Strait A>B ***
	Incidents	**There are statistics difference of incidents among 10 areas**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 21.6864, DF = 9, Pr > Chi-square =0.0099 F-value=3.03, DF = 9, Pr >F =0.0030	**A: South Puget Sound, West Strait of Juan de Fuca, North Puget Sound, Cherry Point, East Strait of Juan de Fuca, Rosario Strait, Guemes Channel B: West Strait of Juan de Fuca, North Puget Sound, Cherry Point, East Strait of Juan de Fuca, Rosario Strait, Guemes Channel, Saddlebag, San Juan Islands, Haro Strait A>B ***
by Season	**Total Events**	**Tug/barge had more total event frequency in winter and summer seasons than in autumn and spring seasons**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 27.8035, DF =3, Pr<0.0001 F-value=16.03, DF = 3, Pr >F <0.0001	**A: Winter Summer B: Autumn Spring A>B ***
	Accidents	**Tug/barge had more accident frequency in winter and summer seasons than in spring and autumn seasons**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 27.2958, DF =3, Pr<0.0001 F-value=18.59, DF = 3, Pr >F <0.0001	**A: Winter Summer B: Spring Autumn A>B ***
by Flag (U.S. Flag vs. Non U.S. Flag)	**Total Events**	**Vessels from U.S. have higher events frequency than those from Non-U.S.**	Wilcoxon	Statistic 187.0000, Normal Approximate z= 3.9874, Pr> z<0.0001	**U.S.>Non U.S. ***
	Accidents	**Vessels from U.S. have higher accidents frequency than those from Non-U.S.**	Wilcoxon	Statistic 185.0000, Normal Approximate z= 3.8822, Pr> z=0.0001	**U.S.>Non U.S. ***
	Incidents	**Vessels from U.S. have higher incidents frequency than those from Non-U.S.**	Wilcoxon	Statistic 185.5000, Normal Approximate z= 3.9837, Pr> z <0.0001	**U.S.>Non U.S.***

Test		Results	Test Used	Statistics	Direction
by Owner	**Total Events**	**Vessels from different owners had statistics difference of total event frequency**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 10.7222, DF =3, P=0.0145 F-value=4.69, DF = 3, Pr >F =0.0090	**A: Foss; Crowley; Olympic tug/barge Inc. B: Crowley; Olympic tug/barge Inc; Island tug/barge Co A>B ***
	Accidents	**Vessels from different owners had statistics difference of accident frequency**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 11.0232, DF =3, P=0.0178 F-value=4.56, DF = 3, Pr >F =0.0098	**A: Foss; Crowley; Olympic tug/barge Inc. B: Crowley; Olympic tug/barge Inc; Island tug/barge Co A>B ***
By Hull Type	**Total Events**	**Single hull tug/barge had higher number of total event frequency than those had double hull**	Wilcoxon	Statistic 187.0000, Normal Approximate z= 4.0172, Pr> z <0.0001	**Single hull > Double hull ***
	Accidents	Single hull tug/barge had higher number of accident frequency than those had double hull	**Wilcoxon**	**Statistic 187.0000, Normal Approximate z= 4.1158, Pr> z<0.0001**	**Single hull > Double hull ***
	Incidents	**Single hull tug/barge had higher number of incident frequency than those had double hull**	Wilcoxon	Statistic 185.0000, Normal Approximate z= 3.9220, Pr> z< 0.0001	**Single hull > Double hull ***
By Accident /Incident Type	**Accidents**	**Accidents caused by pollution had statistically higher number of frequency than those caused by other types**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 52.8120, P>Chi-square <0.0001 F-value= 29.29, Pr >F <0.0001	**Pollution>Allision>Grounding, Collision, Fire, Capsize, Flooding, Sinking , Breakaway***
	Incidents	**Incidents caused by equipment failure had statistically higher number of frequency than those caused by other types**	Kruskal-Wallis Tukey's HSD	Chi-square statistic 17.8887, P>Chi-square =0.0013 F-value= 7.76, Pr >F <0.0001	**Equipment failure>Loss of Propulsion, Loss of steering, Near miss, Structural Failure ***
by Error Type (HOE vs. Mechanical)	**Total Events**	**Tug/barge vessels had more events caused by HOE than by MF**	Wilcoxon	Statistic 94..5000, Normal Approximate z=-2.1139, Pr> z=0.0345	**MF>HOE ***
	Accidents	**Tug/barge vessels had more accidents caused by HOE than by MF**	Wilcoxon	Statistic 157.0000, Normal Approximate z=2.0825, Pr> z<0.0373	**HOE>MF ***
	Incidents	**Tug/barge vessels had more incidents caused by MF than by HOE**	Wilcoxon	Statistic 68.5000, Normal Approximate z= -3.9529, Pr> z<0.0001	**MF>HOE ***

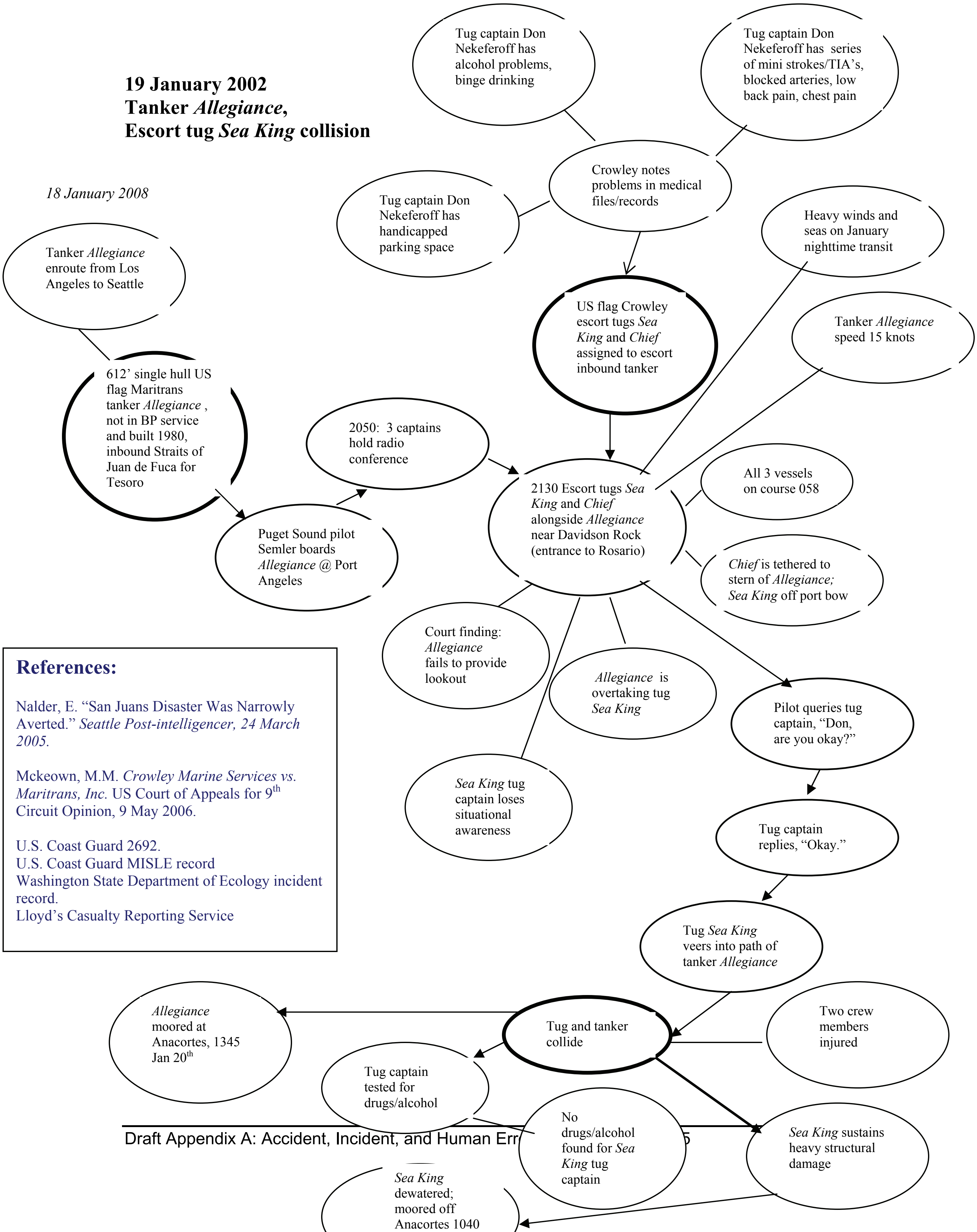
* = small sample size

Appendix A-3

Influence Diagrams for Puget Sound Tanker, ATB/ITB Calibration Accidents, Sample Incidents and Unusual Event, 1995-2005

19 January 2002
Tanker *Allegiance*,
Escort tug *Sea King* collision

18 January 2008



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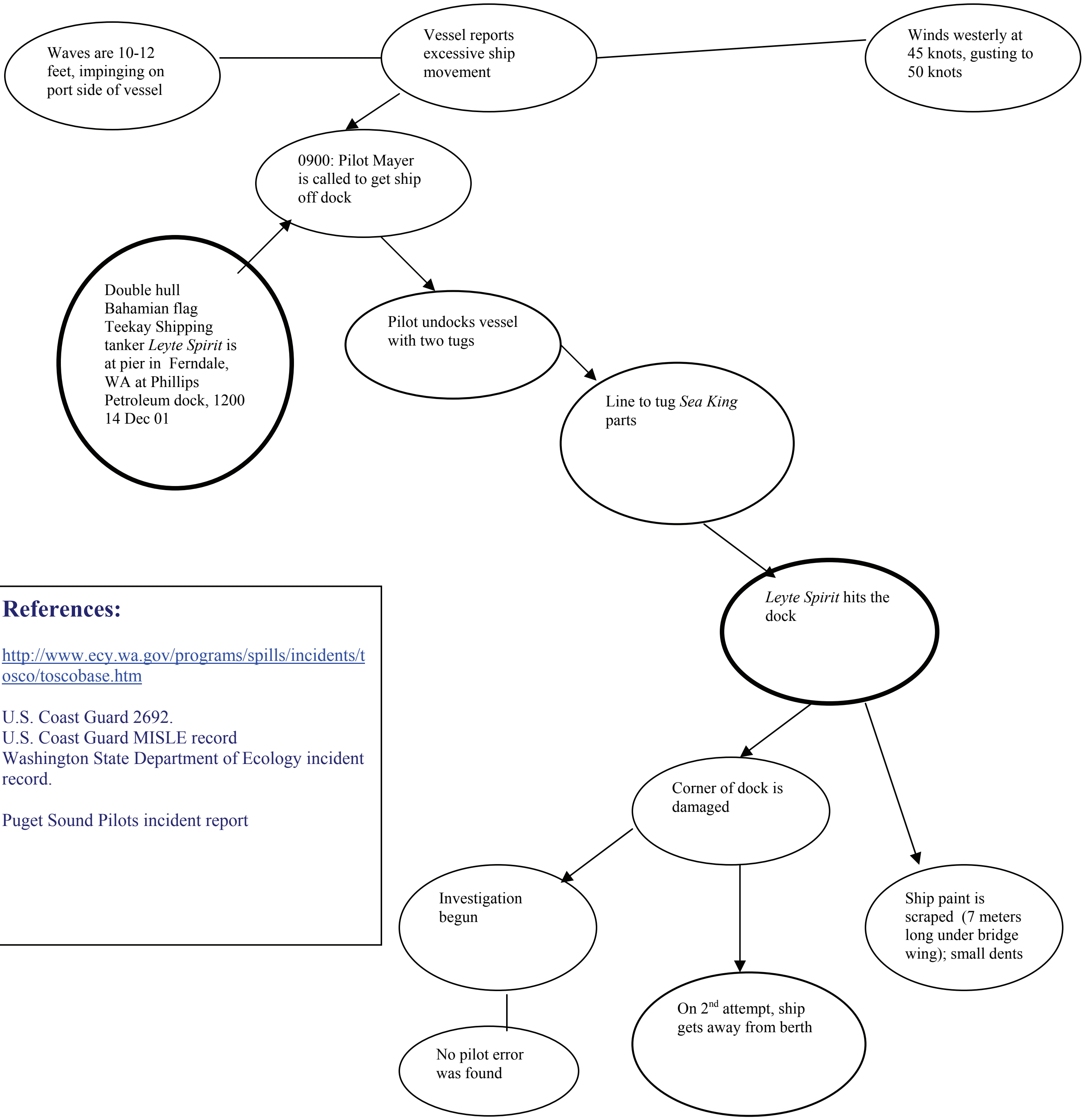
U.S. Coast Guard 2692.
U.S. Coast Guard MISLE record
Washington State Department of Ecology incident record.
Lloyd's Casualty Reporting Service

14 Dec 2001
Tanker *Leyte Spirit*, allision

18 January 2008



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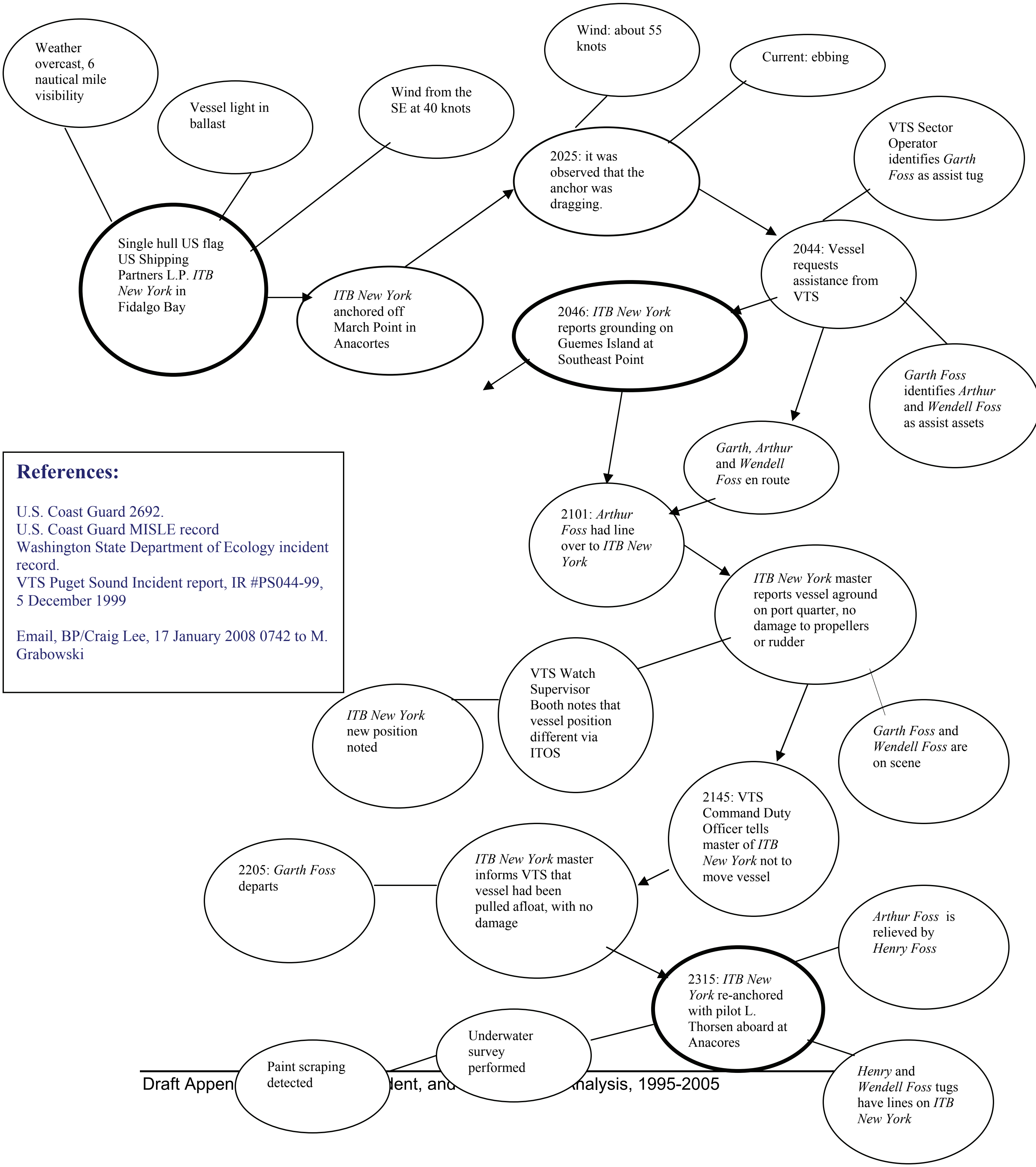
http://www.ecy.wa.gov/programs/spills/incidents/tosco/toscobase.htm

U.S. Coast Guard 2692.
U.S. Coast Guard MISLE record
Washington State Department of Ecology incident record.

Puget Sound Pilots incident report

5 December 1999
***ITB New York*, grounding**

18 January 2008

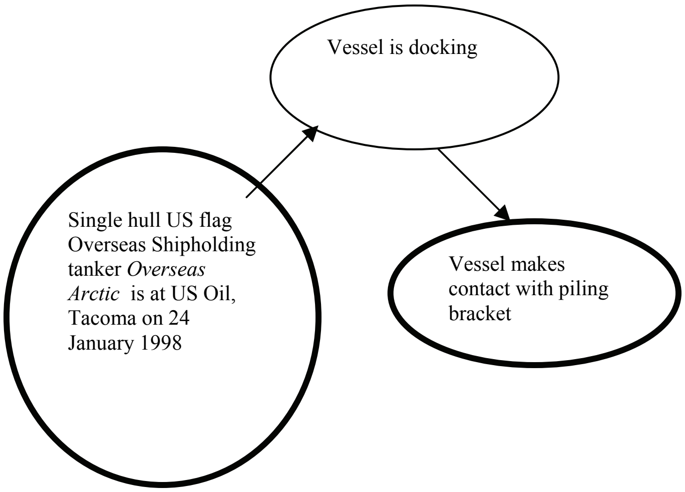


References:

U.S. Coast Guard 2692.
U.S. Coast Guard MISLE record
Washington State Department of Ecology incident record.
VTS Puget Sound Incident report, IR #PS044-99, 5 December 1999

Email, BP/Craig Lee, 17 January 2008 0742 to M. Grabowski

24 January 1998
Tanker *Overseas Arctic*, allision *18 January 2008*



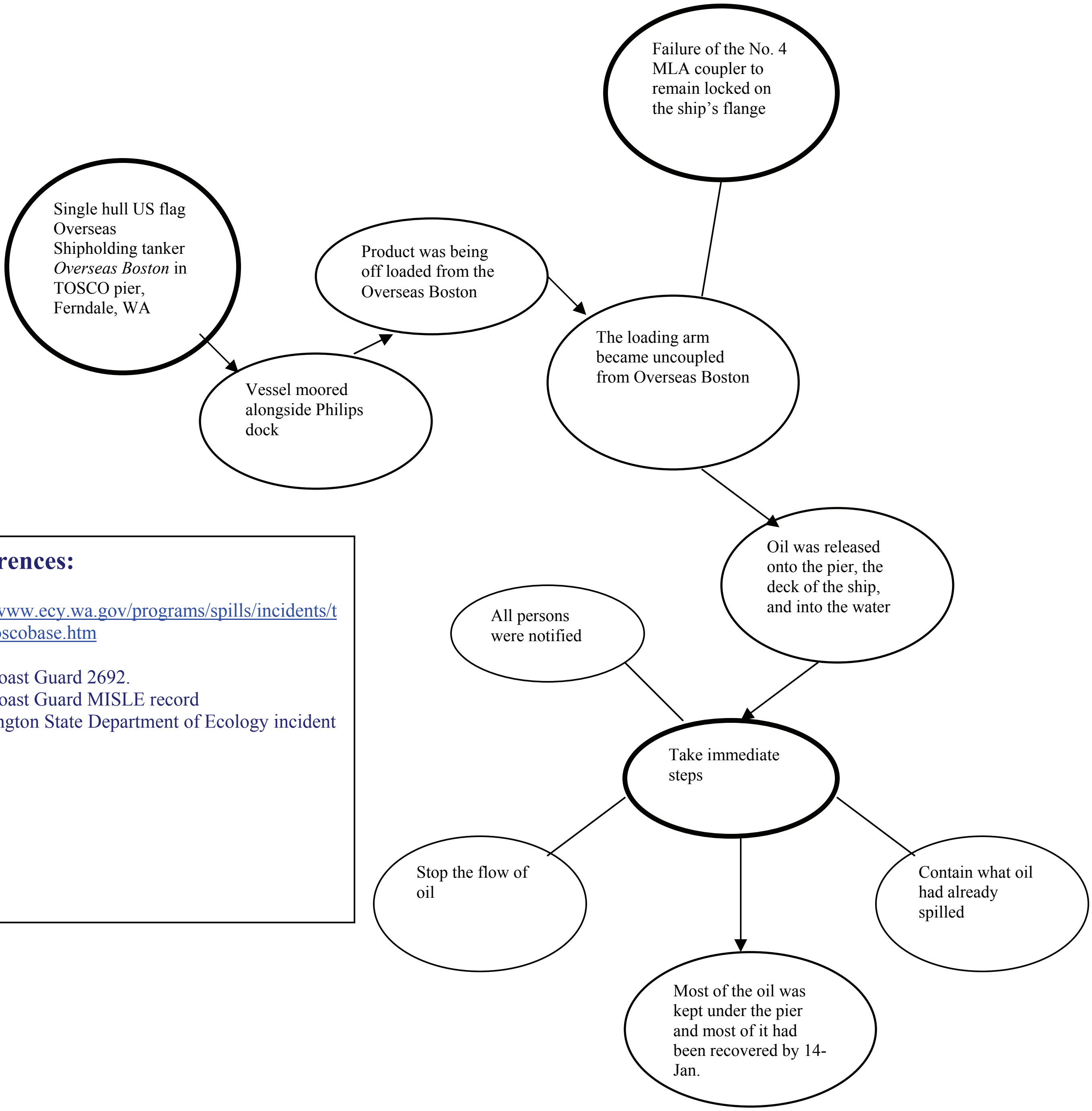
References:

U.S. Coast Guard MISLE record

Puget Sound Pilot Commission record 190906

BP/Steve Alexander phonecon 17 January 2008 1000 to M Grabowski

13 January 2002
Tanker *Overseas Boston*, pollution

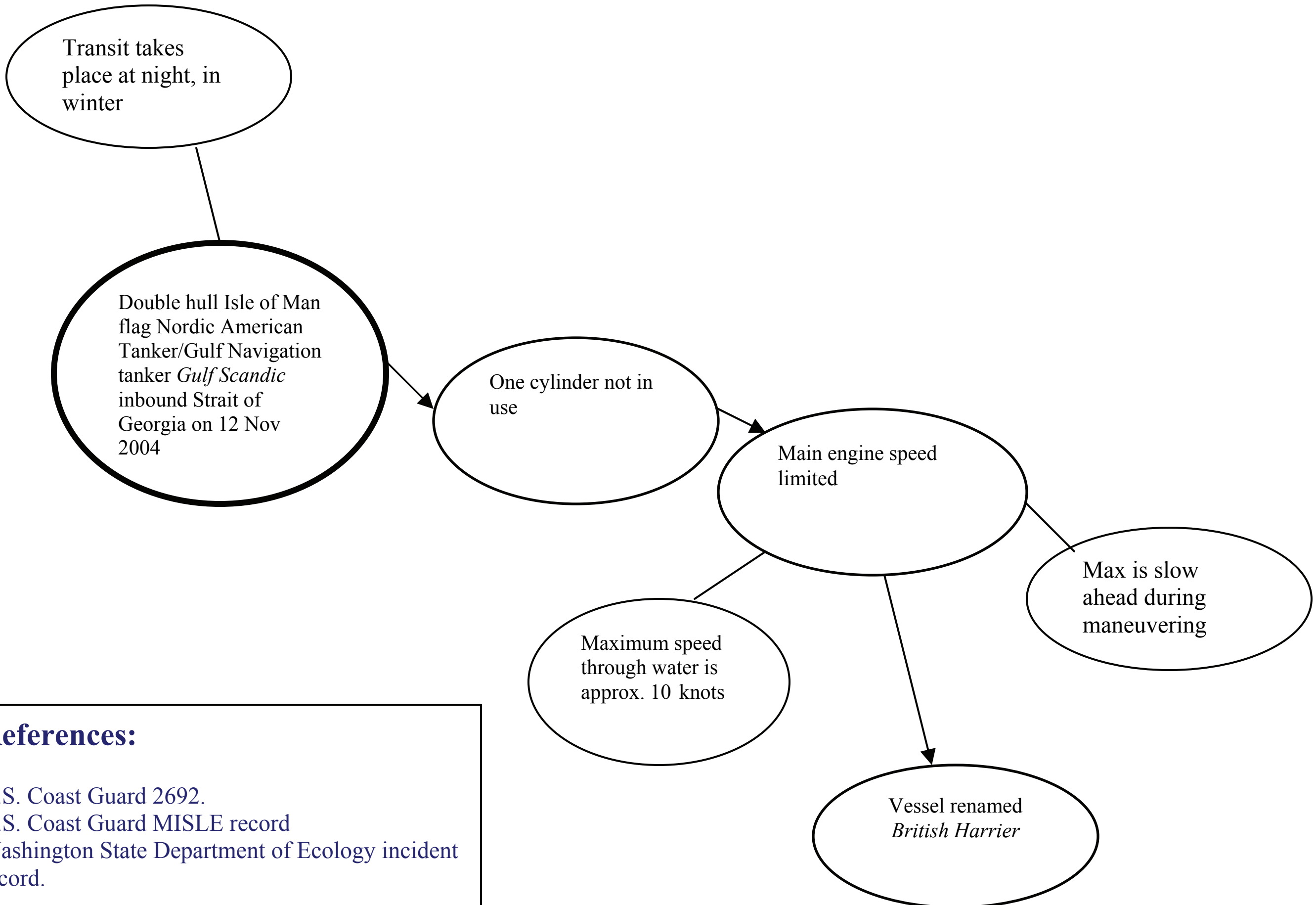


References:

http://www.ecy.wa.gov/programs/spills/incidents/tosco/toscobase.htm

U.S. Coast Guard 2692.
U.S. Coast Guard MISLE record
Washington State Department of Ecology incident record.

12 November 2004
Tanker *Gulf Scandic*, Propulsion Failure *18 January 2008*



References:

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U.S. Coast Guard MISLE record
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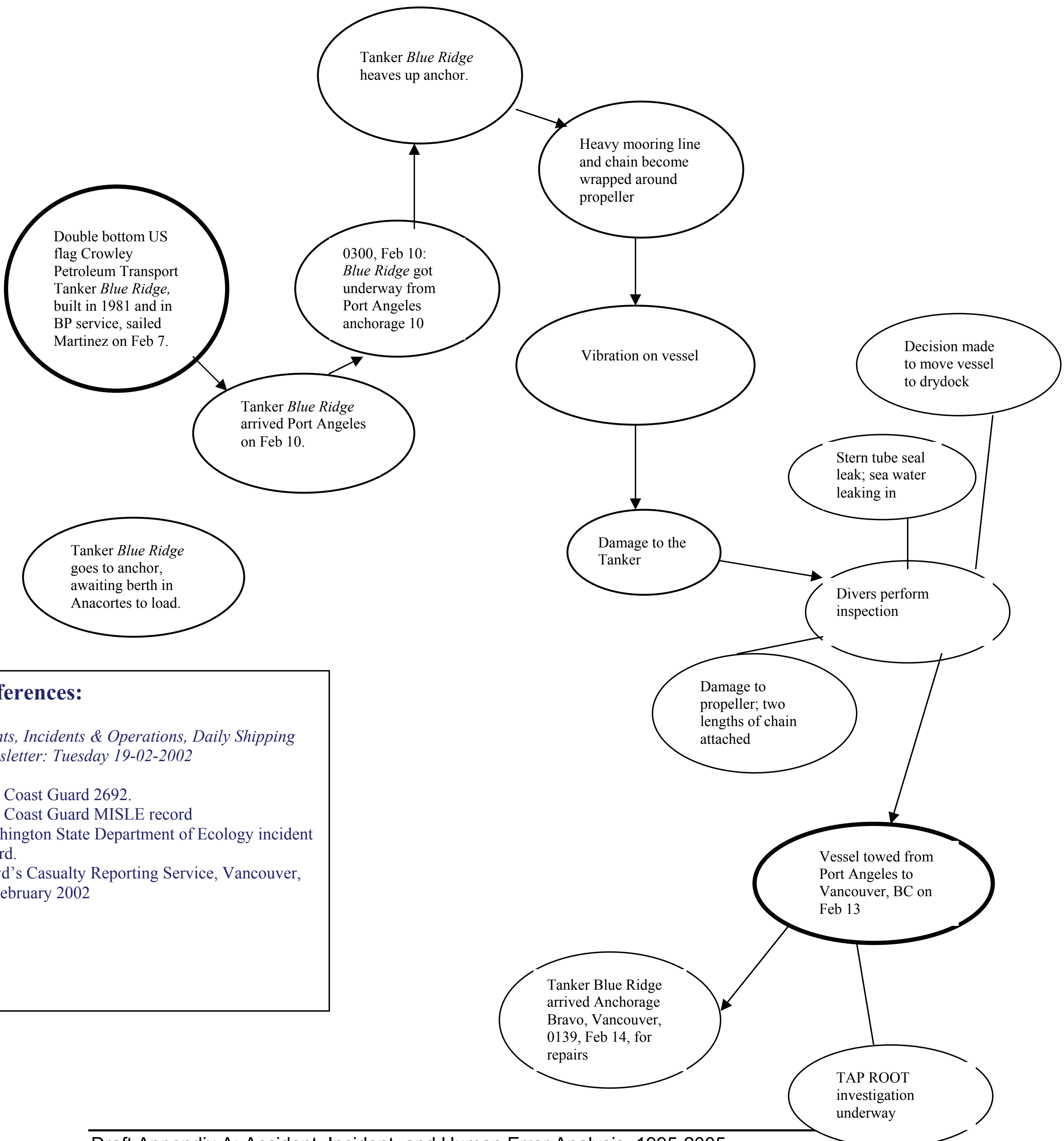
BP/Steve Alexander phonecon with M. Grabowski, 17 January 2008 1000EST

11 February 2002
Tanker *Blue Ridge*, Unusual Event
Wire in propeller

18 January 2008



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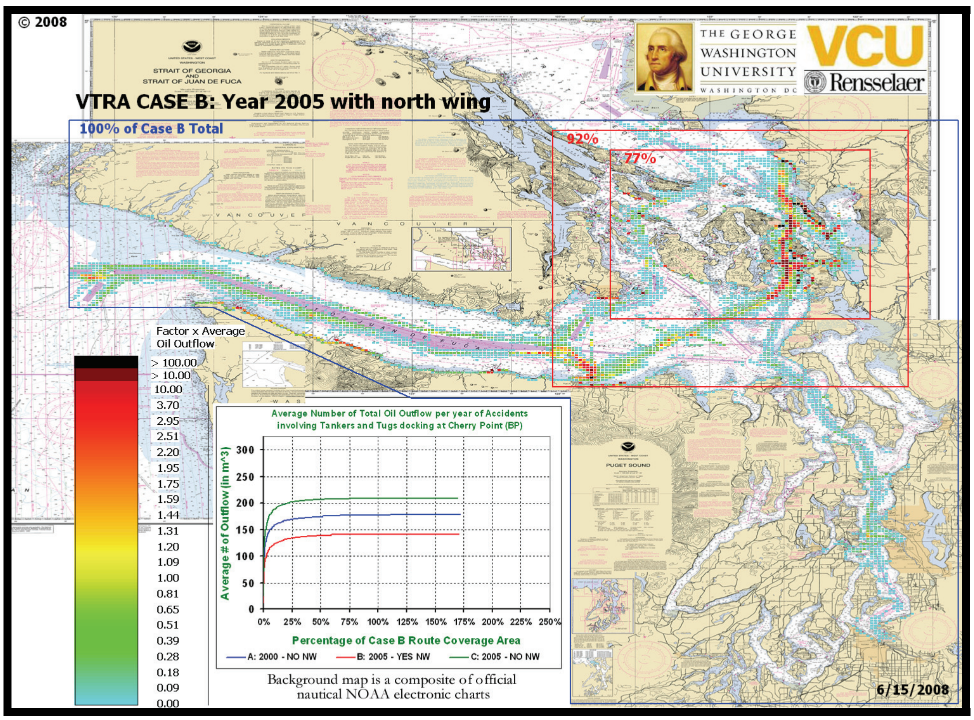
Washington State Department of Ecology incident record.
Lloyd's Casualty Reporting Service, Vancouver, 14 February 2002

TECHNICAL APPENDIX B: SYSTEM DESCRIPTION



Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington

Submitted by VTRA TEAM:

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Jason R.. W. Merrick (VCU) and Martha Grabowski (RPI)

August 31, 2008

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B-1. Introduction

This system description has four primary purposes: 1) define the waters of the Vessel Traffic Risk Assessment (VTRA) study area, 2) describe the climate, geology and topography of the VTRA study area, 3) describe vessel traffic operation in the VTRA study area, and define segments of this traffic considering in the VTRA, 4) describe the management policy and technological infrastructure governing the operations of vessel traffic considered n the VTRA.

B-2. Waters of the Vessel Traffic Risk Assessment

For the purposes of the VTRA, this system description considers the waters of: Puget Sound, Strait of Juan de Fuca, San Juan Islands, and the Strait of Georgia. In the aggregate these waters are referred to as *"the waters of the VTRA"*. The waters of the VTRA are defined within the context, and for the purposes, of data collection for the VTRA, and may not directly correlate with commonly cited maritime lexicon or taxonomy. For the purposes of the VTRA these waters are further delineated into the following sub-systems (see Figure 1, pg 3 for illustration of region):

B-2.1. Juan de Fuca-West:

These waters encompass the western portion of the Strait of Juan de Fuca, and are bounded to the east by a line running south from a point on the northern shore at 48 18.764 N Latitude, 123 33.505 W Longitude. These waters extent west of this eastern boundary through the Juan de Fuca and beyond Cape Flattery to a point approximately 8-miles west of the "J" buoy. The western boundary is intended to encompass the beginning of the traffic separation zone at the entrance of the Strait of Juan de Fuca, and is defined as bounded by a line running north-south 8 nm west of the "J" buoy, as well as by a line running east-west at a point 8nm south of the "J" Buoy. The "J" Buoy is located at 48 29.610 N Latitude, 124 59.973 W Longitude. The waters of Juan de Fuca-West that are west of Cape Flattery are coastal waters with no notable natural restrictions to navigation. The waters of Juan de Fuca-West east of Cape Flattery are inland waters. This eastern portion of Juan de Fuca-West averages 10-miles wide between two parallel shorelines for 45 miles, transiting Cape

Flattery to the eastern boundary. There are no notable restrictions to navigation in these waters.

B-2.2. Juan de Fuca-East:

These waters encompass the eastern region of Strait of Juan de Fuca not defined as Strait of Juan de Fuca-West. These waters are roughly elliptical in shape, with major and minor axes measuring 31-miles (east-west) and 16-miles (north-south), respectively. Within these waters there are multiple submerged and partially submerged shoals and islands. To the north is the San Juan Island Archipelago. To the south is the Puget Sound. To the east is Whidbey Island.

B-2.3. Puget Sound

For the purposes of the VTRA the waters of Puget Sound are delineated as Puget-North, and Puget Sound-South.

Puget Sound-North: The waters of Puget Sound-North encompass all of Admiralty Inlet and those portions of Puget Sound to a southern boundary running west from Meadow Point (47 41.771 N 122 24.588 W) to the shore of Bainbridge Island, and Possession Sound south of the lighthouse at 48 00.951 N 122 16.210 W. Excluded are the waters of Hood Canal, Port Orchard, Sinclair Inlet and Rich Passage, Agate Passage. Within the Puget Sound-North there are multiple bays, inlets, shoals, greater and lesser islands and multiple major and minor towns, cities and ports, including the Ports of Everett, Edmonds and Townsend. The waters are, in general, open to navigation with limited natural restrictions in or near the traffic separation lanes.

Puget Sound-South: The wasters of Puget Sound-South extend from the southern boundary of Puget Sound-North, encompassing the waters of Commencement Bay and Dalco Pass. Excluded are the waters of Colvos Pass. Within the waters of Puget Sound-South there are multiple bays, inlets, shoals, greater and lesser islands and multiple major and minor towns, cities and ports, including: Ports of Seattle, Tacoma, and Ballard. The waters of Puget Sound-South are, in general, a relatively wide, deep sinuous body of water with few restrictions to navigation in the main shipping lanes.

B-2.4. Haro Strait-Boundary Pass

The waters of Haro Strait and Boundary Pass connect the waters of Strait of Juan de Fuca-East and the Strait of Georgia, transiting along the eastern shore of Victoria Island and the western most extend of the San Juan Islands archipelago. These waters are delineated as Haro Straight and Boundary Pass. Geographically and bathymetrically Boundary Pass and Haro Strait are similar, with multiple shoals and islands restricting navigation to channels three quarters of a mile wide at some locations.

Haro Strait: The waters of Haro Strait transit approximately 16-miles in a north-northwesterly direction from Juan de Fuca-East at an average width of 2-miles and depth ranging between 100 and 1000 feet.

Boundary Pass: The waters of Boundary Pass begin at the northern most point of Haro Strait, transiting in a north-northwest for approximately 13-miles.

B-2.5. Rosario Strait

The waters of Rosario Strait transit between the waters of the Strait of Juan de Fuca-East and Georgia Strait along the eastern edge of the San Juan Island archipelago. These waters are bounded to the north and south by the lines of latitude: 48 24.5 N, and 48 41.2 N. The approximant distance between the north and south boundaries is 21 nm. Depths in Rosaria Strait are typically greater than 200 feet. There are multiple shoals and lesser islands restricting navigation to channels three quarters of a mile wide at some locations.

B-2.6. Cherry Point

The waters of Cherry Point are wholly contained within the Strait of Georgia, bounded to the south by the San Juan Island Archipelago, and to the north by Pt Whitehorn (at latitude 48 53.5 N). Depths are commonly 250 to 600 feet, with one notable exception of Alden Bank where depth contours rapidly shallow to less than 50-feet. The Cherry Point British Petroleum refinery facility is located on the eastern shore of these waters. There are multiple docking facilities associated with this facility spread across the shoreline between 48 51.879 N 122 45.264 W and 48 49.628 N 122 42.764 W.

B-2.7. SaddleBag

The waters of SaddleBag transit in a southeasterly directly between Lummi Island (to the north) and St Clair and Guemes Islands (to the south). Bellingham Bay is included in these waters. Depths generally range between 80 and 200 feet with open and wide navigable channels, though lesser islands and shoals do restrict the width of navigable channels to one quarter mile at SaddleBag Island.

B-2.8. Guemes Channel

The waters of Guemes Channel transit between Guemes Island and Fidalgo Island, connecting Saddlebag and Rosario Straits. Depths range between 40 and 100 feet. Independent of the shallow depth, there are no shoals or islands in the shipping lanes to further restrict navigation. These waters encompass the Port of Anacortes and the Shell-Tesoro facilities off-shore of March Point.

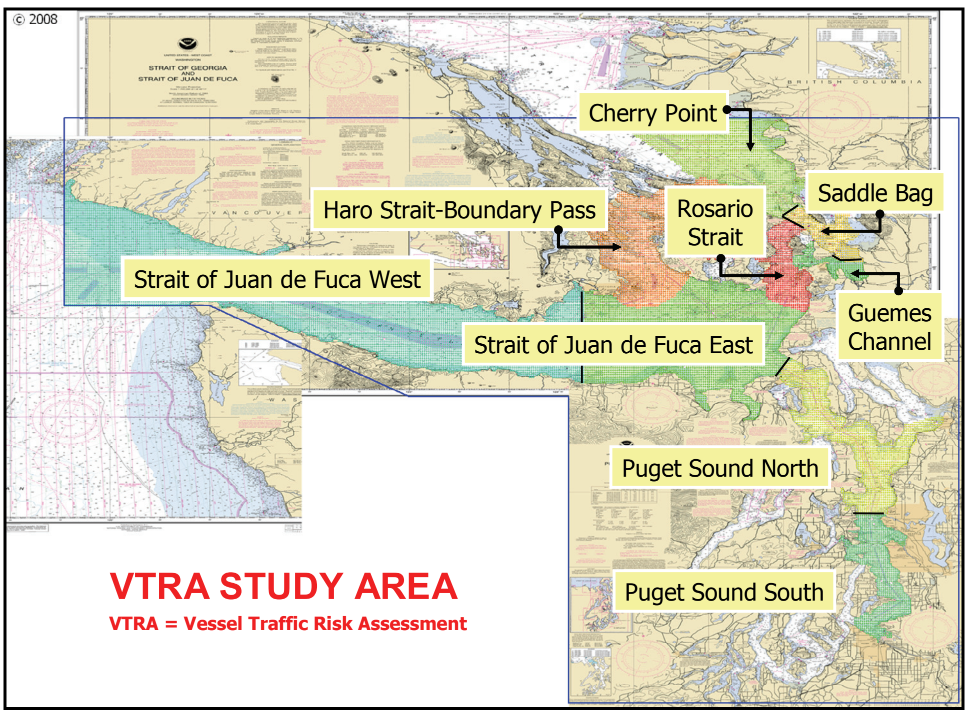


Figure B-1. A map defining the named areas used in the study.

Figure B.1 shows the defined locations.

B-3. Weather, Climate, Topography and Geology

The waters defined in this system description are generally deep throughout, until closer to the shore where elevations can change rapidly from sea level to mountainous terrain. Because the VTRA study area spans a geographic area of approximately 16,000 square miles, prevailing weather characteristics can vary from area to area. In general, the weather and climate is driven by the proximity to the Pacific Ocean (to the west) and the Cascade Mountain Range (to the east). The climate is divided by two seasons: the winter season spans between October and March, and is considered the rainy season with annual rainfall ranging between 40 and 80 inches. The winter climate is largely driven by the winter lows traveling easterly from the Pacific Ocean. The summer season spans March to October when winds and rains are tempered but sea fog can be prevalent (US DOC pg 475).

B-3.1. Wind

B-3.1.1. Straits of Juan de Fuca and Georgia and the San Juan Islands

Winds tend to be strongest during the winter season when they are driven by numerous winter storms that move through the region. As low pressure systems approach the coast winds tend to strengthen, sometimes reaching gale force from the southeast. After storms pass, winds tend to veer to the southwest or northwest. Gale force winds usually last for less than 1 day. Intervals between storms normally range from 1 to 5 days but might extend up to 2 weeks if a strong high-pressure system centers on the region. (US DOC pg 475).

During the summer season (October through March) winds at the Pacific entrance to the Strait of Juan de Fuca are generally out of the southeast to southwest. Gales force winds typically blow for 4 to 6 days per month. The strong southeasterly winds can interact with westerly seas, causing state of confused seas off Cape Flattery. The frequent storm winds from the south make the Vancouver Island coast between Cape Cook and Port San Juan a dangerous lee shore. Winds are generally strongest and gales more frequent in the west end of the Juan de Fuca. In the east end of Juan de Fuca gales occur about 2 to 4 days per month. An approaching storm will often drive strong easterly winds in the central part of the Strait. This condition can drive a "…drainage of air from the Georgia Strait, so that winds near…" the boundaries of Juan de Fuca East and West entrance are frequently from the north or northeast. Winds near the Cape Flattery can reach 65 knots, gusting 90 knots. Throughout Juan de Fuca East and West, winds can be 50 knots with gusts reach 80. (US DOC pg 475)

B-3.1.2. Puget Sound

Puget Sound is open to the north and south, but protected to the west and east by mountains. This geography drives prevailing winds in these waters to be typically southeast or southwest in the summer season, and northeast or northwest in the winter season. Intense storms can generate sustained winds of 40 knots (gusting 50). Winds are strongest in winter season. During the summer season winds are light and variable at night, picking up to 8 to 15 knots during the afternoon. (USDOC pg 513)

B-3.2. Visibility

B-3.2.1. Straits of Juan de Fuca and Georgia and the San Juan Islands

Sea fog is common and dense in the Strait of Juan de Fuca East and West during the later part of the summer season. Land fog causes poor visibility during the winter season. Visibility can be reduced to less than 1-mile for 55 days a year in Juan de Fuca-West, and 35-days in Juan de Fuca-East. Dense fog can remain stationary at the west entrance of Juan de Fuca for days at a time if no winds force it to dissipate. A westerly breeze can push banks of fog towards the southern shore of the eastern end of the strait. (US DOC pg 511)

B-3.2.2. Puget Sound

Poor visibility caused by land fog in Puget Sound is common for 25 or 40 days during the winter season. Generally this fog forms at night and dissipates during the day, though the fog may remain for several days during periods of calm winds. These conditions exist in Puget Sound-North more than Puget Sound-South. (US DOC pg 511)

B-3.3. Tides and Currents

B-3.3.1. Straits of Juan de Fuca and Georgia and the San Juan Islands

The currents may attain velocities of 2 to 4 knots, varying with the range of tide, and are influenced by strong winds. E of Race Rocks, in the wider portion of the strait, the velocity is considerably less. At Race Rocks and Discovery Island the velocity may be 6 knots or more. The flood current entering the Strait of Juan de Fuca sets with considerable velocity over Duncan and Duntze Rocks, but, instead of running in the direction of the channel, it has a continued set toward the Vancouver Island shore which is experienced as far as Race Rocks. The flood current velocity is greater on the N shore of the strait than on the S. The ebb current is felt most along the S shore of the strait, and between New Dungeness Light and Crescent Bay there is a decided set S and W, especially during large tides. With the wind and swell against the current, a short choppy sea is raised near the entrance to the strait.

In Haro Strait and Boundary Pass, the flood current sets N; the ebb current sets in the opposite direction. The ebb usually runs longer and has a greater velocity. At the N entrance to Boundary Pass, the flood sets E along the N and S sides of Sucia Islands and across Alden Bank; the velocity is about 1 to 2 knots. The Current has moderate velocity between Sucia and Orcas Islands. There is a large, daily inequality in the current (see Tidal current Tables for predicted times and velocities). Heavy, dangerous tide rips occur between East Point on Saturna Island and Patos Island, and for two miles N in the Strait of Georgia. Tide rips also occur on the ebb between Henry Island and Turn Point, as well as around Turn Point where the ebb may attain a velocity of 6 knots during large tides. The flood current sets E from Discovery Island across the S end of Haro Strait until close to San Juan Island. This E set especially noticeable during the first half of the flood. Heavy tide rips occur N of Middle Bank as well as on the Bank and around Discovery Island.

B-3.3.2. Puget Sound

In Admiralty Inlet and Puget Sound, the tidal currents are subjected to daily inequalities similar to those of the tides. Velocities of 2 to 7 knots occur from Point Wilson to Point No Point. In the more open waters of the sound S of Point No Point the velocities are much less. At Point Wilson and at Marrowstone Point, slack water occurs from one-half to 1 hour earlier near shore than in midchannel.

In the winter, when S winds prevail, there is generally a N surface drift which increases the ebb current and decreases the flood current. This effect is about 0.5 knot between Nodule and Bush Points. The tidal currents in the S entrance of Possession Sound are weak and variable. Between Foulweather Bluff and Misery Point, the tidal currents have a velocity of about 0.8 knot, while in the S part of Hood Canal, the velocity is only about 0.5 knot; at times of tropic tides, however, the greater ebbs may attain velocities more than double these values. The tidal currents have velocities up to about 6 knots or more in Agate Passage and in The Narrows.

Tides at Seattle have a mean range of 7.7 feet and a diurnal range of 11.4 feet. A range of about 18 feet may occur at the time of maximum tides. (See Tide Tables for daily predictions.) As a rule, the tidal currents in the harbor have little velocity. At times, however, with a falling tide an appreciable current will be found setting NW along the waterfront.

B-4. Maritime Vessel Traffic

The scope of the VTRA is specific to potential impacts of traffic inbound and outbound of the Cherry Point Facility. Within the context of this system description this traffic is referred to as "*Cherry Point Oriented Traffic" (CPO Traffic).* During standard operations in the VTRA study area, CPO Traffic interacts with other traffic that may or may not be inbound to, or outbound from, the Cherry Point Facility. This secondary traffic is referred to in this system description as *"General Traffic*". Because of interactions between these two classifications of traffic, CPO Traffic and General Traffic are both within the scope of this system description. This section of the system description defines and quantifies CPO Traffic, and describes General Traffic that has been approximated in the VTRA exposure study.

B-4.1. Cherry Point Oriented Traffic

For the purposes of the VTRA CPO Traffic is defined as: traffic navigating, at anchor or berthed within the waters of the VTRA study area, whether the traffic is inbound or outbound of the Cherry Point Facility (laden or unladen), independent of wherein the VTRA study area this traffic may be. Such traffic may include tanker vessels, tug-tow-barge, articulated tug-barges and tanker escort vessels. This traffic ceases to be CPO Traffic once this traffic leaves the waters of the VTRA study area as these waters are defined in Section 2.2 of this system description. CPO Traffic is delineated as US-Flagged and Foreign-Flagged vessels for the purposes of modeling and forecasting vessel traffic.

All CPO Traffic is compelled to participate in the Vessel Traffic System Puget Sound (VTSPS). The preponderance of CPO Traffic is compelled to participate in the Vessel Movement Reporting System (VMRS) (these systems are defined in Section 2.5). It is highly likely that all CPO Traffic voluntarily participates in the VMRS, if not compelled. Therefore, no CPO Traffic will be considered General Traffic.

B-4.2. General Traffic

The scope and scale of General Traffic operating within the VTRA Study Area ranges between large US Naval vessels and small personal watercraft. Not all General Traffic is required to participate in the VTS or VMRS systems. Therefore, not all General Traffic is quantifiable as objective data. General Traffic that is compelled to participate in the VMRS will be noted and quantified. General Traffic that is not compelled to participate in VMRS and VTS systems will be estimated through data gathering by direct query of available data sources, including inquiry of individuals with expert knowledge of specific segments of General Traffic.

General Traffic operating within the VTRA study area is delineated by the requirement to participate in the VMRS or VTS systems. There are thee primary sub-categories of General Traffic based on VMRS and VTS participation requirements:

- Vessels over 40-meters that are compelled to actively participate in the VMRS.
- Vessels over 20-meters, but under 40-meters, that are compelled to passively participate in the VTS.
- Vessels under 20 meters that are not compelled to participate in either the VTS or the VMRS.

VMRS Participating General Traffic: VMRS Participating General Traffic (active participants) is further delineated as US-Flagged and Foreign-Flagged General Traffic.

VTS Participating General Traffic: VTS Participating Traffic (passive participants) is assumed captured and quantified with VMRS Participating Traffic. Although VTS passive participating General Traffic is not compelled to actively participate in the VMRS system, modern vessel movement surveillance technologies enable passive participation to be captured as quantified data points (see AIS Section 2.5.4).

Small General Traffic: All vessel traffic not considered CPO Traffic, or compelled to continuously actively or passively participate in the traffic system, is considered to be *Small General Traffic*. Typically vessels under 20-meters in length are not compelled to actively or passively participate in the VMRS or VTS systems, and are considered in the VTRA as *Small General Traffic*. Individual vessels may choice to actively participate in the vessel traffic system, or may at times be passively captured. Because of the inconstant nature of participation, all traffic below 20-meters in length will be quantified and modeled separately from non-Small General Traffic, unless considered to be CPO Traffic.

As it is assumed that neither PG Traffic nor CG Traffic is captured in the VMRS or VTS system, identifying and quantifying this traffic is a function of interacting with local experts of individual user groups. Individuals from primary user groups are queried to estimate annual vessel movements within the VTRA study area.

Small General Traffic is further delineated as: Small Private General Traffic (SPG Traffic) and Small Commercial General Traffic SCG Traffic.

Small Private General Traffic: Private General Traffic (PG Traffic) is further delineated as Permitted and Non-Permitted PG Traffic.

Permitted SPG Traffic: Permitted SPG Traffic is delineated as 1) Sailing Regattas and Sailing Races, 2) Powerboat Races, 3) Maritime Parades, 4) Sport Fishing Events. A review of permits issued by the United States Coast Guard Puget Sound Marine Safety Office demonstrated that calendar year 2005 as representative of a typical year for Permitted SPG Traffic activity for purposes of quantifying magnitude, path and time of movement.

Non-Permitted SPG Traffic: Non-Permitted SPG Traffic is loosely defined as traffic that operates within the VTRA study area as singular and independent vessels, cooperating in organized gathering of vessels to only a very limited scale. This traffic is further delineated as 1) Cruising and Sailing, 2) Sport Fishing. With this definition, it is assumed that there are no content experts for the whole of the VTRA study area. No attempt has yet been made to quantify vessel movements in the VTRA study area.

Small Commercial General Traffic: Small Commercial General Traffic (SCG Traffic) is delineated as: 1) state commercial fisheries, 2) tribal commercial fisheries, 3) Canadian commercial fisheries, and 4) non-fisheries commercial traffic. State commercial, tribal commercial and Canadian commercial fisheries are very similar in nature, yet have been delineated in this system description to allow traffic movements to be forecasted as a function of allocation of marine resource allocations tribal and non-native commercial fishers.

State Commercial Fisheries Traffic: State Commercial Fisheries Traffic is delineated by species sought and gear-type utilized by state commercial fishers:

- Crab
- Salmon Seine
- Salmon Gillnet
- Shrimp Beam Trawl
- Shrimp Pod

These commercial fisheries are governed by the Washington Department of Fish and Wildlife (WDF&W). Through conversations with WDF&W personnel, the commercial fisheries delineated in this section were determined as the largest and most representative of total State Commercial Fisheries fleet. The vessels involved in the individual fisheries vary in size, speed, gear-type utilized, region of the VTRA study area and time of year. The methodology for quantifying this diverse body of traffic is as an interview process, wherein subject matter experts are queried for the information (or data) that will allow a series of traffic movement rules to be established within the VTRA exposure model. Specific information sought includes:

- Fishery
- Number of vessels
- Time of year actively participating in commercial fishery

- Location of fishery
- Typical transit activities between home port (intra-fishery port-of-call) and fishing grounds
    - Time of day
    - Period in transit
- Movements during fisheries (within region identified as fishing grounds)

Tribal Commercial Fisheries Traffic: Tribal Commercial Fisheries Traffic is delineated by species sought and gear-type utilized by Tribal commercial fishers:

- Crab
- Salmon Seine
- Salmon Gillnet
- Halibut

The Tribal Commercial Fisheries are governed by the individual tribal organizations. Each tribal organization is allocated some proportion of the total allowable catch for individual species through annual negotiates with the WDF&W during the Pacific Fisheries Management Council. Individual tribal organization's allocation for each species is dependent on a tribal organization's "Usual and Accustom Rights" to that resource. This situation leads to a fragmented fishery effort and thus a need to interact with a large number of tribal fisheries experts in order to identify and quantify Tribal Commercial Fisheries vessel traffic movement. Efforts have been made to contact each tribal organization individually in order to identify and quantify the fisheries effort for the tribal organization. For those tribal organization that have participated in this process, subject matter experts where queried for the following information:

- Fishery
- Number of vessels
- Time of year actively participating in commercial fishery
- Location of fishery
- Typical transit activities between home port (intra-fishery port-of-call) and fishing grounds
    - Time of day

    - Period in transit
- Movements during fisheries (within region identified as fishing grounds)

Canadian Commercial Fisheries Traffic: The Canadian commercial fishers are not delineated as Tribal (termed First Nations) and non-tribal fisheries. This is because the Canadian Department of Fisheries and Oceans (DFO) holds regulatory authority over both user groups, thus the DFO fishery managers are the singular competent authority for all commercial fisheries.

The Canadian commercial fishery fleet incorporates a diverse body of vessel types operating in the Canadian regions of the VTRA study area. The DFO was contacted in October 2007 to initiate a conversation pertaining to modeling the movement of this fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area (see Systems Description) was utilized to determine the segments of the commercial fishing fleet that would be considered for further investigation. These were identified by species and gear-type:

- Salmon-Seine
- Salmon-Gillnet
- Shrimp-Pod
- Crab-Pod

The competent managerial authority for all Canadian Commercial fisheries in the VTRA Study Area is housed in the Victoria office of the DFO. This office was contacted and elicited for data pertaining to typified movements of the commercial fishery fleet over which the manager had regulatory authority. An initial meeting took place in December 2007. This initial meeting began an iterative process through which data was elicited, compiled and returned in order to develop a series of rules that would allow typified fleet movements to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type
    - regulatory boundaries of fishery
    - regulatory times of fishery
        - time of year (months)

    - time of day (day light, clock, 24 hour)
  - typical distribution of fleet across regulatory area
  - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
    - time of day of transits
  - number and type of vessel participating in fishery
    - number of vessel participating as a function stage of fishery
      - first third
      - second third
      - final third
    - typified design of participating vessel
      - length
      - draft
      - fuel capacity
      - speed

The DFO fisheries managers participating in this process were long-term DFO employees, with a body of in-office and on-water managerial experience that would allow them to offer insight to specific and general habits of the commercial fishing fleet and commercial fishers.

Whale watching: There is a robust commercial whale watching industry that typically operates in the region of the San Juan Islands Archipelago. Commercial whale watching vessels that participate on a daily bases can number in the hundreds at the height of the summer season, with vessels transiting the waters of Straits of Georgia, Rosario Strait, Haro Strait, Boundary Pass and Juan de Fuca-East as J and K pods of Orca Whales migrate the region. The US/Canadian international boundary is typically transparent to the commercial whale watching vessels that transit from near all port cities in the region, with US and Canadian fleets freely mixing in all locations during whale watching activities.

Unlike the commercial fisheries, there is no specific US or Canadian government competent regulatory authority with the body of knowledge that would allow the commercial whale watching fleet to be modeled. Therefore, raw data pertaining to the commercial whale watching fleet was obtained through a publicly accessible database developed and maintained Sound Watch (as part of The Whale Museum).

Sound Watch is a privately funded boater education program, with no regulatory authority over the commercial whale watching fleet. However, the intent and purpose of Sound Watch is to observe and document the activities of the whale watching fleet (commercial or private). This documentation process includes capturing specific data pertaining to:

- the number of vessels within a 2-mile radii of the whale-pod at every half hour
- the home port of vessels commonly seen within the 2-mile radii of the whale pod
- the location of the whale pod documented every half hour as Latitude and Longitude.

B-5. Traffic Management Protocols and Technological Infrastructure

The traffic management protocols and accompanying technological infrastructure in the VTRA study area are robust; integrating standard maritime navigation and communication protocols, with direct observation and management of maritime vessel movements in Puget Sound, Strait of Juan de Fuca, San Juan Island Archipelago and Straits of Georgia. Elements of these systems that are critical to the development of the VTRA are described in this section of this system description.

Within the VTSPS coverage area are adjoining United States and Canada territorial waters. Boundaries between these waters are at times transparent to the vessel traffic transiting the VTSPS area. To minimize potential for conflicts between potentially variant navigation rules and jurisdictional control, the Cooperative Vessel Traffic Service (CVTS) was established to allocate oversight and control over adjoining waters. All waters defined as being within the VTRA study area are referred to as the waters of the VTSPS. Exceptions are noted when dictated in order to consider the CVTS.

B-5.1. Vessel Traffic Service - Puget Sound

The Vessel Traffic Service-Puget Sound (VTSPS) is defined as the traffic management protocols and physical infrastructures utilized in the geographic region wherein the rules and regulation contained in CFR Title 33 Parts 160 and 161 are applicable (Vessel Traffic

Service-Puget Sound Region [VTSPS Region]). The VTSPS Region is defined in Subpart C of the Vessel Traffic Service-Puget Sound User Manual. The VTRA study area, in it entirety, is considered within the VTSPS Region. The VTSPS is comprised of three major components (VTSPS User Manual): 1) Vessel Movement Reporting System (VMRS), 2) Traffic Separation Scheme (TSS) and 3) Surveillance systems

B-5.1.1. Vessel Movement Reporting System

The VMRS is the system of communication and navigation protocols and technologies through which the requisite traffic control authority monitors and controls traffic movement in the VTSPS area. The communication system is VHF-FM frequency based, with participating vessels communicating on specific frequencies dependent on location (see Vessel Traffic Service-Puget Sound Region [VTSPS Region]).

There are two classes of traffic regulated to participate in the VMRS:

Vessel Movement Reporting System Users: Vessel Movement Reporting System Users (VMRS Users) are also referred to as 'active participants' in the VTSPS. Active participants are required to communicate with the Vessel Traffic Center (or other requisite authority depending on location – see Section 2.4.2) while underway in the VTSPS area. VMRS Users are defined as:

1) all power-driven vessels of 40 meters or more while underway and navigating.
2) Every commercial vessel engaged in towing 8-meters or more in length while underway and navigating
3) Every vessel certificated to carry 50 or more passengers for hire when engaged in trade.

Note: Canadian regulations dictate that vessels over 20 meters participate as active participants in the VMRS

Vessel Traffic System Users: Vessel Traffic System Users (VTS Users) are also referred to as 'passive participants' in the VTSPS. Passive participants are required to (at a minimum) continuously monitor appropriate VHF-FM VTS frequency while navigating in the VTSPS area (Channels 5A or 14 dependent on location) as well as VHF Channel 13. VTS Users are defined as:

1) every power driven vessel of 20 meters or more, but less than 40 meters.
2) Every vessel of 100 gross tons or more carrying 1 or more passengers for hire, while navigating
3) A dredge of floating plant engaged in or near a channel or fairway in operations likely to restrict or affect navigation of other vessels.

Note: Canadian regulations dictate that vessels over 20 meters are active participants in the VMRS

B-5.1.2. Traffic Separation Scheme

The Traffic Separation Scheme (TSS) is an internationally recognized and accepted system for maintaining separation between inbound and outbound traffic. Where the TSS is active, the body of water is delineated into two traffic lanes with a separating zone between the lanes. Navigation rules governing vessel movements (such as entering and crossing the traffic lanes, and overtaking vessels within the traffic lanes) are defined in Rule #10 of the International Collision Regulations (1972 COLREGS) (VTSPS User Manual).

In addition to requirements under 1972 COLREGS, additional navigation rules are defined in the VTSPS User Manual when navigating Rosario Strait and Guemes Channel (VTSPS User Manual).

B-5.1.3. Surveillance Systems

The Vessel Traffic Center in Seattle receives radar signals from 12 radar sites that are placed across the full extent of the VTSPS area. Radar provides approximately 2,900 square miles of coverage including the Strait of Juan de Fuca, Rosario Strait, Admiralty Inlet, and Puget Sound south to Commencement Bay. There are also close circuit cameras at locations of know high density traffic.

A recent addition to the surveillance system includes the Automatic Information Systems (AIS), which continuously relay AIS equipped vessel's name, description, vector and destination to all similarly AIS equipped vessels within transmission range, as well as VTS Puget Sound.

B-5.2. Cooperative Vessel Traffic Service for the Juan de Fuca Region (CVTS)

The waters of the CVTS Region are defined in Subpart C of the VTSPS User Manual. The purpose of the CVTS is to jointly manage vessel traffic in the Juan de Fuca region. The Strait of Juan de Fuca is delineated by the United States and Canadian boarder into northern and southern sections. The CVTS is the vessel traffic management system established and jointly operated by the United States and Canada within these waters to ensure continuity of vessel traffic and regulation oversight, as well as to minimize jurisdictional conflicts (cite VTSPS User Manual).

Vessels navigating within Canadian Territorial waters in the Strait of Juan de Fuca are required to follow traffic rules defined by Seattle Traffic. Canada maintains jurisdictional control over investigation of violation of Seattle Traffic defined navigation rules (cite VTSPS User Manual).

B-5.3. Pilotage Requirements

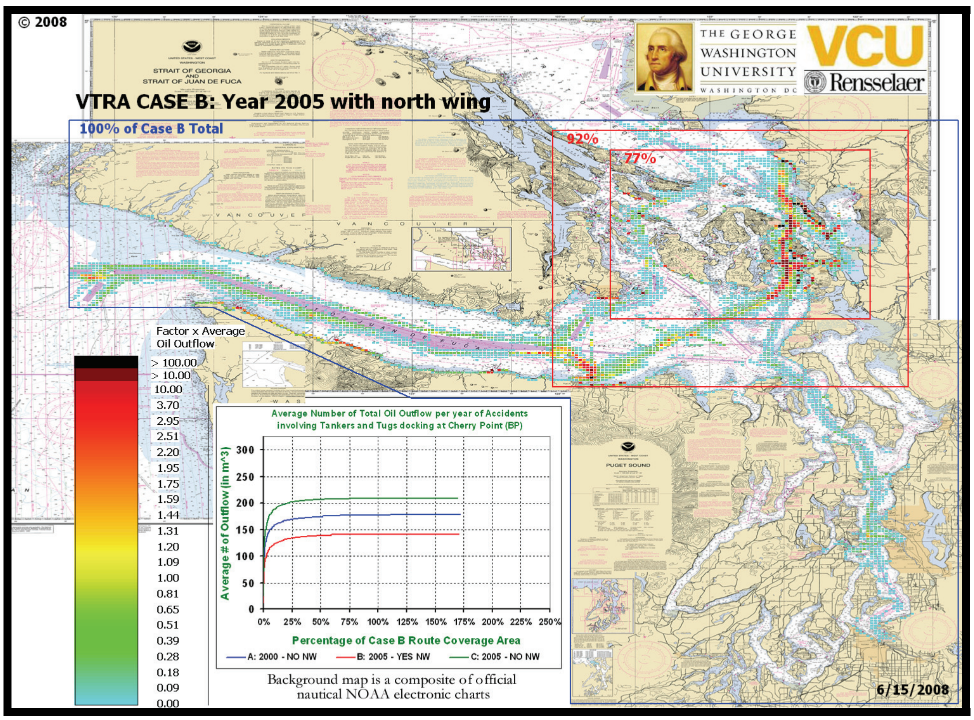
Pilotage, Strait of Juan de Fuca and Puget Sound Pilotage is compulsory for all foreign vessels and U.S. vessels engaged in foreign trade. Pilotage is optional for U.S. vessels engaged in the coastwise trade with a federally licensed pilot on board.

Puget Sound Pilots serve all U.S. ports and places E of 123°24'W., including Port Angeles, Puget Sound, and adjacent inland waters. Port Angeles has been designated as the pilotage station for all vessels enroute to or from the sea. The pilot station is located on Ediz Hook about 0.7 mile W of Ediz Hook Light (see chart 18468). There are two pilot boats, both are 22 meters in length with white hulls and orange houses. The standard day and night signals are displayed.

B-5.4. Escort Requirements

Vessels transporting crude oil or petroleum products that are over 40,000 DWTs are required to have a tug escort beyond a point east of a line between Discovery Island and New Dungeness Light.

TECHNICAL APPENDIX C: SIMULATION CONSTRUCTION



Assessment of Oil Spill Risk due to Potential Increased Vessel Traffic at Cherry Point, Washington

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C-1. VTS Traffic Modeling

In 1979 by formal agreement, the Canadian and the United States Coast Guards established the Co-operative Vessel Traffic System (CVTS) for the Strait of Juan de Fuca region. The purpose of the CVTS is to provide for the safe and efficient movement of vessel traffic while minimizing the risk of pollution by preventing collisions and groundings and the environmental damage that would follow.

C-1.1. The Vessel Traffic Operation Support System (VTOSS) repository

Within our study area, vessels are tracked by multiple VTS centers, including those at Tofino, Vancouver, and Victoria for the Canadian Coast Guard and Seattle for the US Coast Guard. Tofino Traffic provides VTS for the offshore approaches to the Juan de Fuca Strait and along the Washington State coastline from 48 degrees north. Seattle Traffic provides VTS for both the Canadian and US waters of Juan de Fuca Strait and Victoria Traffic provides VTS for both Canadian and US waters of Haro Strait, Boundary Passage, and the lower Georgia Straits. Figure C-1 shows the breakdown of the areas of responsibility in the shared areas. Seattle VTS is also responsible for all areas south of those marked.

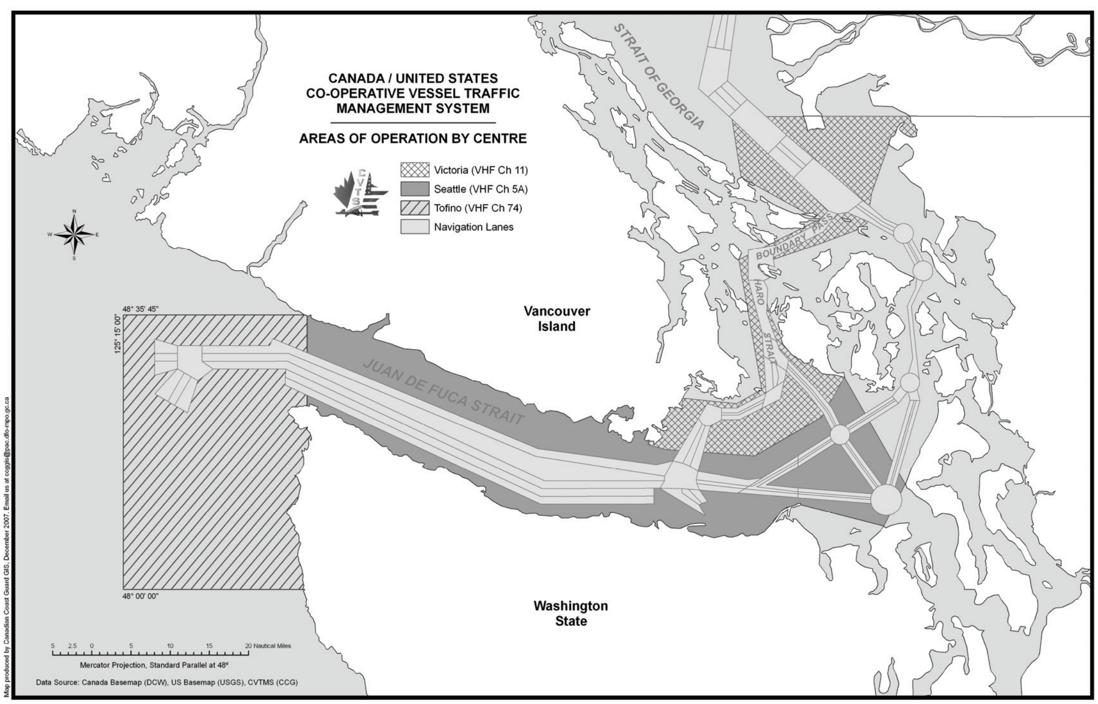


Figure C-1. The Cooperative Vessel Traffic Management System.

The requirements for a vessel to report to the VTS are:

(a) Every power-driven vessel of 40 meters (approximately 131 feet) or more in length, while navigating;

(b) Every commercial towing vessel of 8 meters (approximately 26 feet) or more in length, while navigating;

(c) Every vessel certificated to carry 50 or more passengers for hire, when engaged in trade.

The VTS records the transit and also monitors the movement of vessels on screens in their operating center. Each VTS receives radar signals from strategically located radar sites throughout their defined area of responsibility. Additionally, close circuit TV provides coverage of various critical waterways. The newest ship location technology is the Automatic Identification System (AIS).

Table C-1. A sample of records from the VTOS database.

TK041101														
LAST_UDDTG	VSL_ID	NAME	CALLSIGN	LLOYDS_ID	FLAG	TYPE_DEC	POS_LAT	POS_LONG	COURSE	SPEED	POS_SRC	CVTS_ZONE	FROM_AT	NEXT_TO
200405311538	VSSL20010321162640	GOA	VTST	8511665		BULK CARRIER	48.278	123.42	19	12.7	RDR	VIC	PORTL	CONST
200405311538	VIC720010925142443	HECATE PRINCE	CY7049	0320279	CA	TUG	49.42	123.765	116	4	RDR	VIC	PEARS	NORTH
200405311538	CSTL19931231000526	EVCO SPRAY	CY8295	0323624	CA	TUG	49.683	124.55	0	0	MAN	VIC	BEALE	TILBU
200405311538	UNK120040507103108	VICTORIA EXPRESS II	WDB6455		US	FERRY	48.43	123.357	0	0	RDR	VIC	VICTO	
200405311538	CSTL19931231002612	COMOX CROWN	CZ4330	0348790	CA	TUG	49.158	123.498	252	6	RDR	VIC	VANCO	CROFT
200405311538	CSTL19940124102341	QN OF OAK BAY	VG8234	7902283	CA	FERRY	49.258	123.687	74	20.5	RDR	VIC	DEPAR	HORSE
200405311538	CSTL19940112170039	COHO	WN4599	5076949	US	FERRY	48.342	123.392	166	13.9	RDR	VIC	VICTO	PORT
200405311538	VIC620010513123854	ISLAND EXPLORER 2	WDCS		US	MISCELLANEOUS	48.85	123.192	112	14.2	RDR	VIC	ANACO	ANACO
200405311538	CSTL19931231001069	PERSUADER			CA	TUG	48.585	123.278	0	0	RDR	VIC	D ARC	
200405311538	CSTL19931231002350	SS MONARCH	VY7687	7636028	CA	TUG	49.128	123.06	0	0	MAN	VIC	VANCO	BISHO
200405311538	TOF119991226223416	GANGES HAWK			CA	MISCELLANEOUS	48.71	123.398	191	16.9	RDR	VIC	MINER	SWART
200405311538	VSSL19961029133558	SCHOLARSHIP		0809734	CA	MISCELLANEOUS	48.852	123.485	0	0	MAN	VIC	GANGE	PORT
200405311538	CSTL19931231002357	SS NAVIGATOR	VDPW	7043324	CA	TUG	49.308	123.452	293	8.4	RDR	VIC	NORTH	ALASK
200405311538	CSTL19931231002375	SS VICTOR	VDPB	7041247	CA	TUG	49.282	123.712	52	4.1	RDR	VIC	GABRI	WOODF
200405311538	CSTL19931231002338	SS CHAMPION	VDPS	7041235	CA	TUG	49.732	124.777	0	0	MAN	VIC	NODAL	VANCO
200405311538	CSTL19931231002348	SS FOAM	CY9631		CA	TUG	48.42	123.393	0	0	RDR	VIC	PRODU	VICTO
200405311538	CSTL19931231002320	NA CHAMPION	CFC6672	7406681	CA	TUG	49.148	123.03	0	0	MAN	VIC	LAFAR	STEVE
200405311538	CSTL19940124101906	QN OF COQUITLAM	CZ8058	7411155	CA	FERRY	49.293	123.47	267	21.2	RDR	VIC	HORSE	DEPAR
200405311538	CSTL19931231002373	SS VALIANT	CY9526	7005889	CA	TUG	49.458	124.127	0	0	RDR	VIC	BLIND	GABRI
200405311538	CSTL19931231002351	SS KING	VGXJ	6823052	CA	TUG	49.402	123.457	0	0	RDR	VIC	ANDYS	SOUTH
200405311538	CSTL19931231002534	CARRIER PRINCESS	CZ3582	730647	CA	RAIL FERRY	49.143	123.038	0	0	RDR	VIC	TILBU	NANAI
200405311538	CSTL19960505113116	HMCS WINNIPEG	CGAI	338	CA	WARSHIP	48.432	123.442	0	0	MAN	VIC	ESQUI	CONST
200405311538	CSTL19931231000573	STORM COASTER	CY3040	8137079	CA	TUG	49.198	122.9	0	0	MAN	VIC	RIVTO	NEW W
200405311538	TOF119991226223416	GANGES HAWK			CA	MISCELLANEOUS	48.852	123.485	0	0	MAN	VIC	GANGE	MINER
200405311538	CSTL19931231002336	SS CAVALIER	CZ5656	7434808	CA	TUG	49.125	123.203	302	11.6	RDR	VIC	SYLVA	VANCO
200405311538	CSTL19960505112549	HMCS NANAIMO	CGAV	702	CA	WARSHIP	48.34	123.298	270	6.9	RDR	VIC	CONST	
200405311538	CSTL19931231000484	HARMAC CEDAR	CY7692	0323250	CA	TUG	49.32	123.458	138	1.9	RDR	VIC	BLIND	NORTH

This involves a shipboard broadcast that relies on the global positioning system to get an accurate position, heading, and speed, and transponders to send out this information to other vessels and shore-based receiving equipment for the VTS centers. Each VTS center, therefore, can track vessels in their area by both radar (if the vessel is in line of site of a radar station) and AIS. The VTS centers record the tracks of the vessels that report in. This information is sent to a central data repository called the Coast Guard Vessel Traffic Operation Support System (VTOSS). This database consists of records of the longitude, latitude, heading, speed, vessel type, name, call sign, Lloyd's ID, departure port, destination port, and positional data source (AIS or Radar) every 3-7 minutes of a vessel's transit. Table C-1 shows a sample of records and the major columns in the VTOSS database. The entire VTOSS repository includes all Canadian VTS centers as well as Seattle Traffic from the US Coast Guard, meaning all position records for the study area are included for the vessels that participate in the VTS.

C-1.2. Turning track data in to simulation routes

The simulation model needs two pieces of information from the VTOSS database. What is the path that a vessel follows? And what is the date and time of each vessel's arrival? With these two pieces of information, we can add the vessel to the simulation at the appropriate date and time and then have it navigate through the study area in the simulation. In this manner, we simulate a transit of the vessel.

Each record in the database is the location of a vessel at a given time. A sequence of such records for one transit of a vessel show the path it follows and the first record gives us the date and time of the arrival of the vessel in the study area. However, an examination of Table C-1 shows us that the database gives all vessel location records at a given time for different records. We must sort the database in a different order to get the sequences of records for one vessels transit.

If we re-order the database, by vessel name then we can see all the records for each value of the column vessel name. Then if we sort within each vessel name by date and time, we will see the succession of records for that vessel over time. There are some problems here though. It is possible for two different vessels to share the same name. Their Lloyds ID is unique, but this is sparsely recorded. However, two vessels of the same name in this area will be of different types, so if we sort by vessel type, then by names for each vessel type, then by date and time for each vessel name, then we can separate these vessels. Table C-2 shows a piece of the database sorted in this manner. In some cases, the vessel name was misspelled or entered differently (for instance with a "II" rather than a "2), so these different versions had to be corrected.

Table C-2. The VTOSS database ordered to allow routes to be found.

TYPE_DEC	NAME	TIMESTAMP	FROM_AT	NEXT_TO	POS_LAT	POS_LONG
BULK CARRIER	ABAKAN	38757.1819444444	RUSSI	OLYMP	47.068	122.911
BULK CARRIER	ABAKAN	38757.1861111111	RUSSI	OLYMP	47.062	122.908
BULK CARRIER	ABAKAN	38757.1916666667	RUSSI	OLYMP	47.056	122.907
BULK CARRIER	ABAKAN	38757.1958333333	RUSSI	OLYMP	47.054	122.907
BULK CARRIER	ABAKAN	38757.5069444444	RUSSI	OLYMP	47.585	122.431
BULK CARRIER	ABAKAN	38757.5111111111	RUSSI	OLYMP	47.569	122.443
BULK CARRIER	ABAKAN	38757.5145833333	RUSSI	OLYMP	47.552	122.455
BULK CARRIER	ABAKAN	38757.51875	RUSSI	OLYMP	47.535	122.468
BULK CARRIER	ABAKAN	38757.5229166667	RUSSI	OLYMP	47.516	122.482
BULK CARRIER	ABAKAN	38757.5263888889	RUSSI	OLYMP	47.497	122.495
BULK CARRIER	ABAKAN	38757.5263888889	RUSSI	OLYMP	47.497	122.495
BULK CARRIER	ABAKAN	38757.5326388889	RUSSI	OLYMP	47.469	122.514
BULK CARRIER	ABAKAN	38757.5388888889	RUSSI	OLYMP	47.439	122.523
BULK CARRIER	ABAKAN	38757.5402777778	RUSSI	OLYMP	47.429	122.524
BULK CARRIER	ABAKAN	38763.7	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7041666667	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7083333333	OLYMP	SEAT	47.052	122.906
BULK CARRIER	ABAKAN	38763.7125	OLYMP	SEAT	47.057	122.907
BULK CARRIER	ABAKAN	38763.7173611111	OLYMP	SEAT	47.065	122.908
BULK CARRIER	ABAKAN	38763.7194444444	OLYMP	SEAT	47.068	122.911
BULK CARRIER	ABAKAN	38763.7236111111	OLYMP	SEAT	47.075	122.918
BULK CARRIER	ABAKAN	38763.7277777778	OLYMP	SEAT	47.082	122.925
BULK CARRIER	ABAKAN	38763.7319444444	OLYMP	SEAT	47.089	122.927
BULK CARRIER	ABAKAN	38763.7361111111	OLYMP	SEAT	47.099	122.923
BULK CARRIER	ABAKAN	38763.7409722222	OLYMP	SEAT	47.111	122.916

To derive one path (or route) for a vessel's transit, we start at the first record and see what the ports of departure and destination are. We take the records in sequence until we reach a record from a different transit. But how do we know that a record is from a different transit? Firstly, if the port of departure or destination changes, then we can assume that this is a different transit. Also, if the vessel name or vessel type changes, then we can assume that we have reached a different transit. For some records, these critical fields were blank, so we had to ignore those records. Taking the sequence of locations for this transit, we can then plot the points on our map. This sequence of points is one route. However, this sequence of points taken every 3-7 minutes for a transit from BP Cherry Point to Buoy J and out to sea, for instance, can be very long. If we have routes that are defined by too many points, then the simulation will take too long to run. So we must reduce the number of points without making inaccurate routes. Thus we run through each route taking each sequence of 3 points in a row. If the middle point is on a straight line between the first and third points, then we can remove it. This actually means calculating the perpendicular distance between the middle point and the line between the first and third points. If this distance is less than 0.001 nautical miles, then we remove the middle point. Thus we achieve routes that accurately reflect the paths of the vessels, but without needlessly slowing the simulation. Figure C-2 shows one such route for an oil tanker transiting from BP Cherry Point to South America.

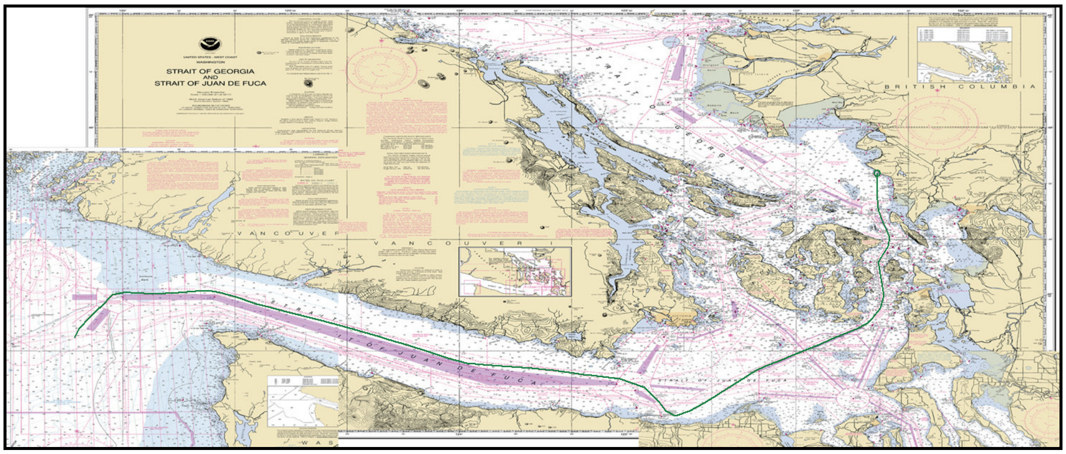


Figure C-2. An oil tanker route from BP Cherry Point to South America

However, not all such routes obtained are as perfect as that shown in C.2. Figure C-3 shows one problem route for a bulk carrier transiting from Anacortes to California. The points on this route are mostly derived from AIS recordings, but towards the end of the Straits of Juan de Fuca, the AIS signal weakened and radar recordings took over for a while. With radar, we can sometimes find blips like those shown. To remove as many of these blips as possible, we found the time between successive points and calculated the maximum distance that a vessel could travel in this time. If we take three points, and the distance between the first and second point is more than a vessel could travel in that time and the distance between the second and third point is greater than a vessel could travel in that time, then we know the middle point is a radar blip and we remove it. This removed many of these problems, but it is possible to have more than one point in a row that is the result of a radar blip, so we had to manually clean the routes by plotting them one by one on the map and writing functions in the simulation program that would allow us to remove specific points.

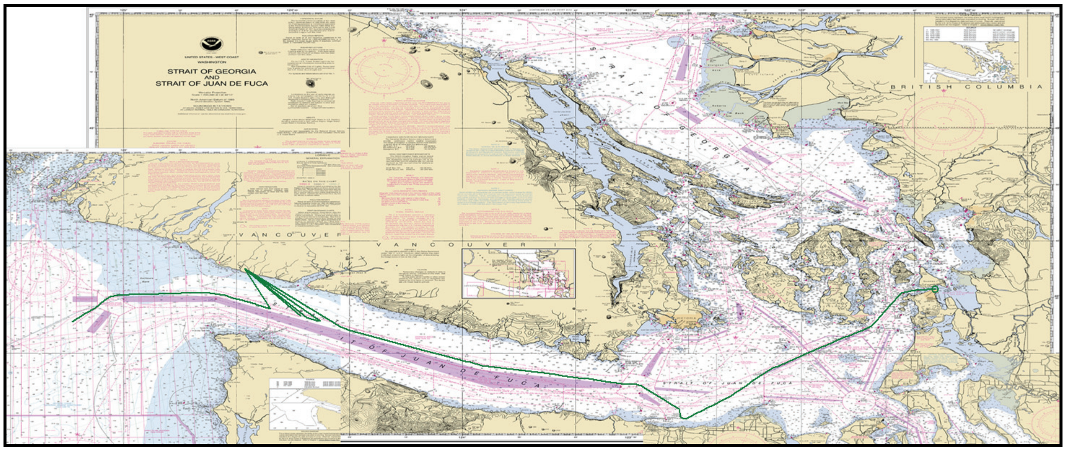


Figure C-3. A bulk carrier route from Anacortes to California

Even with these cleaned routes, we still had problem routes. Figure C-4 shows one such problem. Did the vessel just appear passed Buoy J and then disappear just passed Port Angeles? Examining the sequence of records reveals the problem. This route is for a bulk carrier transiting from Guatemala to Vancouver. As this vessel passed through the system, its location was recorded by different VTS stations as shown in Figure C-1. Tofino recorded the ports of departure and destination as “GUATE” and “VANCOUVER”. Seattle recorded them as “ GT” and “VANCOUVER”. Victoria and Vancouver then went back to “GUATE” and “VANCOUVER”. Thus our approach for finding routes breaks up this transit in to pieces because of the different names used for the same ports.

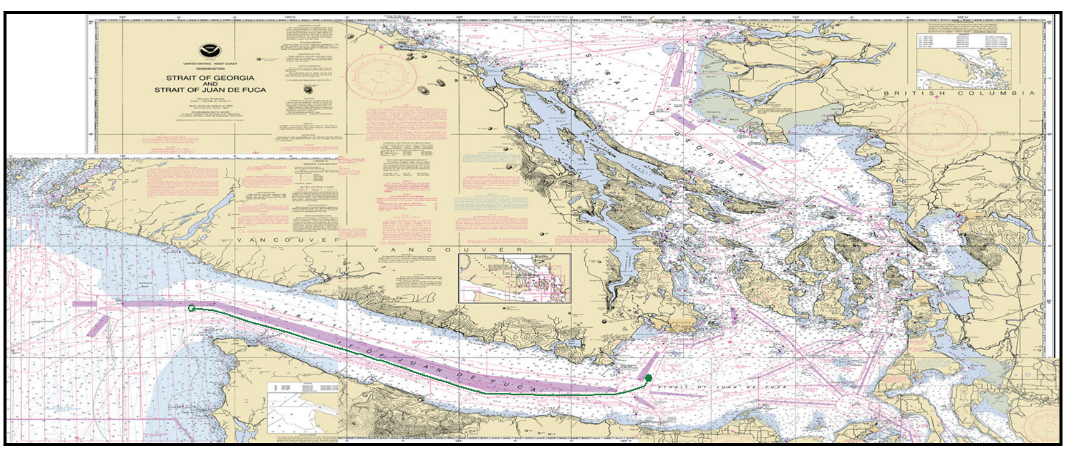


Figure C-4. A bulk carrier from Guatemala to Vancouver.

Obviously in this case, we can simply replace all instances of " GT" with "GUATE" and redo the route to join all the pieces together. This must then be done for all instances of non-unique names for a given port. We took all possible values of the departure and destination port names and sorted them. This showed many such instances of alternative names for the same port, so we determined one unique value for each and replaced all the alternatives for a given port with this unique value. We also found that while, for instance, Seattle VTS might say a vessel is heading for "VANCOUVER", Vancouver VTS might record a specific dock or terminal that the vessel is heading for. Thus we also had to replace all names of places within a given port, with the unique name for that port for ports outside our study area, like Vancouver and Delta port. For ports within our study area, we kept a finer level of detail of the different locations within, for instance, Seattle and Tacoma.

With these steps completed, many of the routes were now smooth and complete. There were, however, missing transits due to recording problems with VTOSS, so a vessel might transit from A to B and then C to D, but with no transit from B to C. There were also still incomplete routes. Thus we chose representative routes. For each type of vessel transiting from A to B, we would find one complete route to use for each such transit in the simulation. This does somewhat discretize the simulation, but without it some transits would be incomplete (leading to inaccuracies in the traffic patterns) and the simulation would run very slowly, which would not allow a complete analysis of the different cases. At first, we tried to automate the selection of routes, but this did not lead to good selection for many routes, so the selection was performed visually for all routes (just over 6,000 in all).

C-1.3. Routes used in the simulation

Figures C.5 to C.12 show the routes used in the simulation. Each figure shows all representative routes used for one type of vessel.

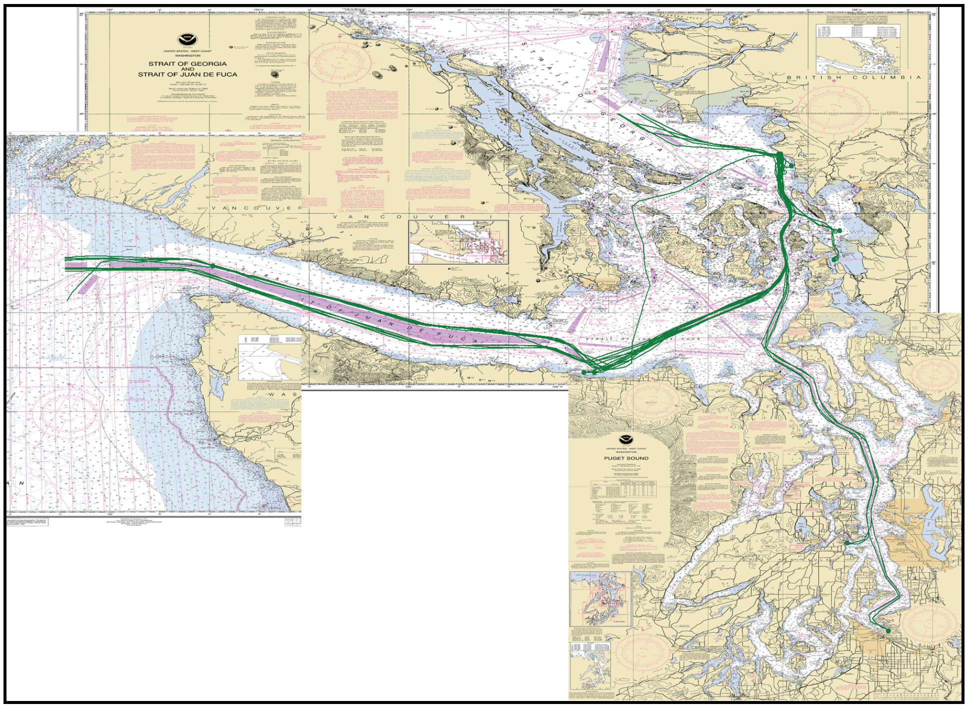


Figure C-5. Representative Routes Used by Tankers Calling at BP Cherry Point.

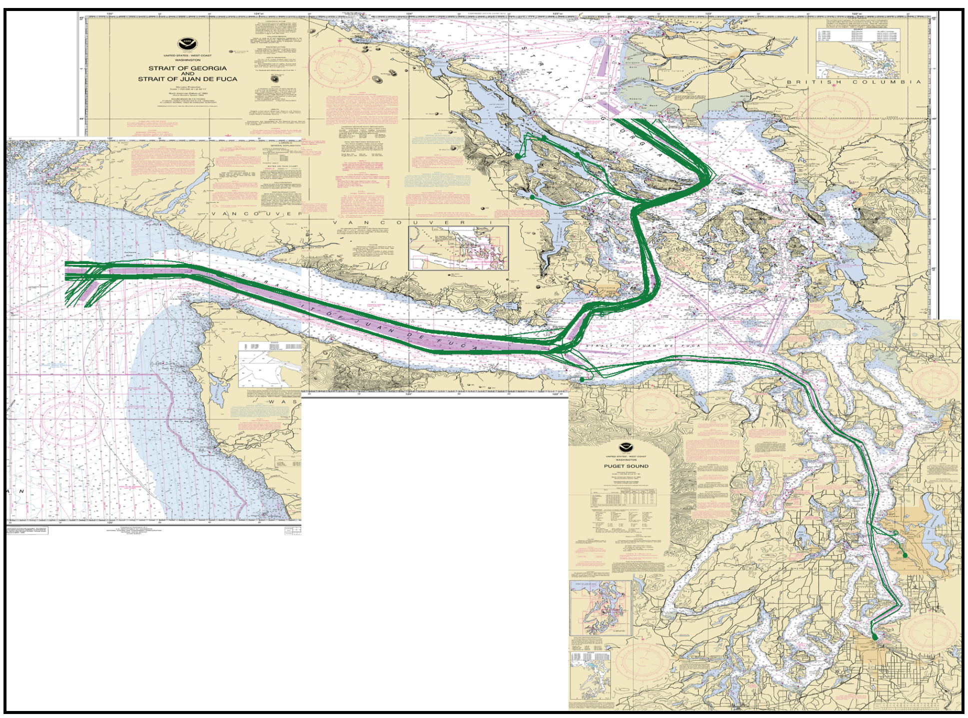


Figure C-6. Representative Routes Used by Bulk Carriers.

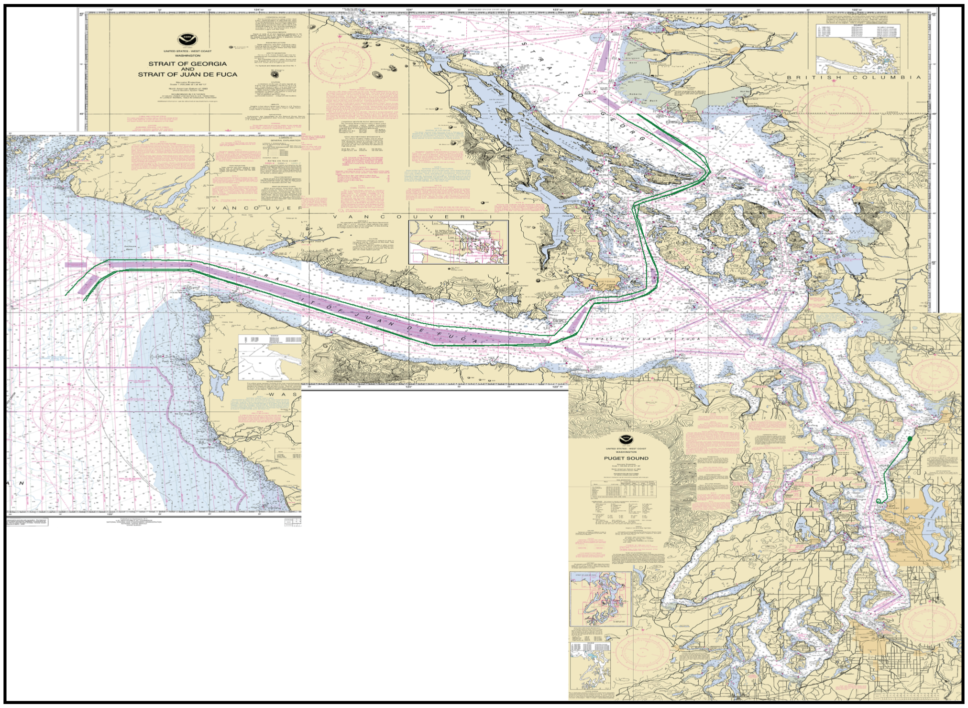


Figure C-7. Representative Routes Used by Chemical Carriers.

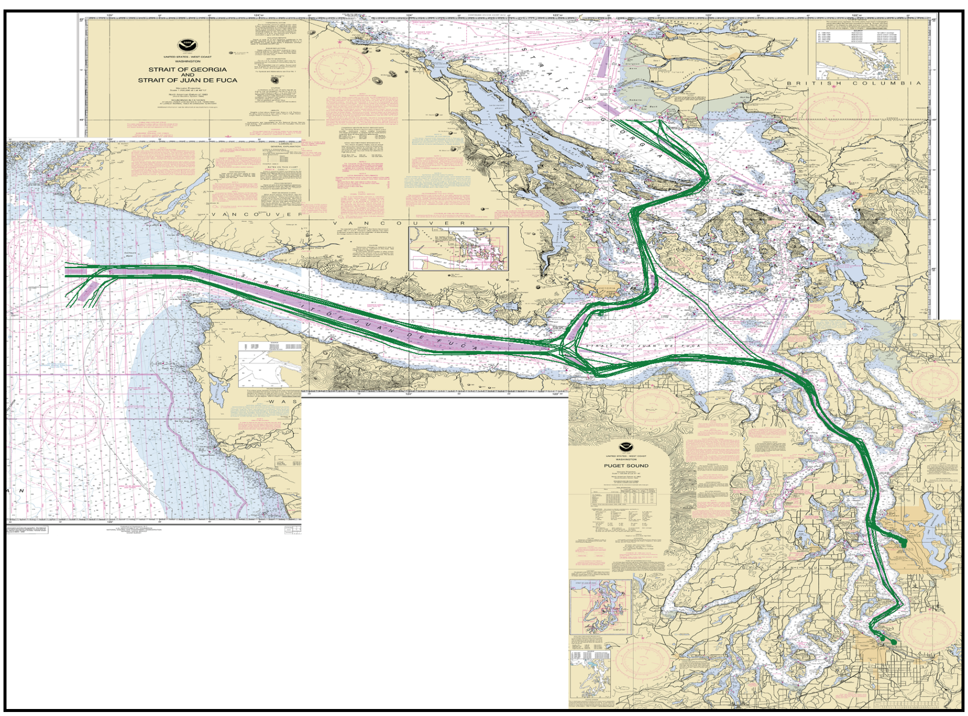


Figure C-8. Representative Routes Used by Container Vessels.

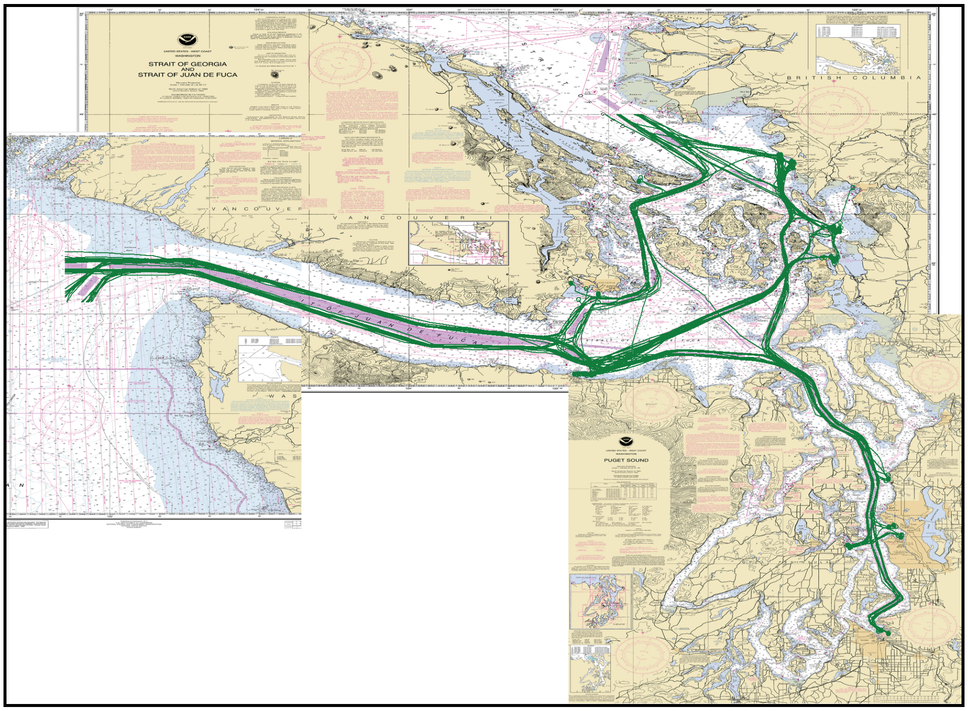


Figure C-9. Representative Routes Used by all Oil Tankers.

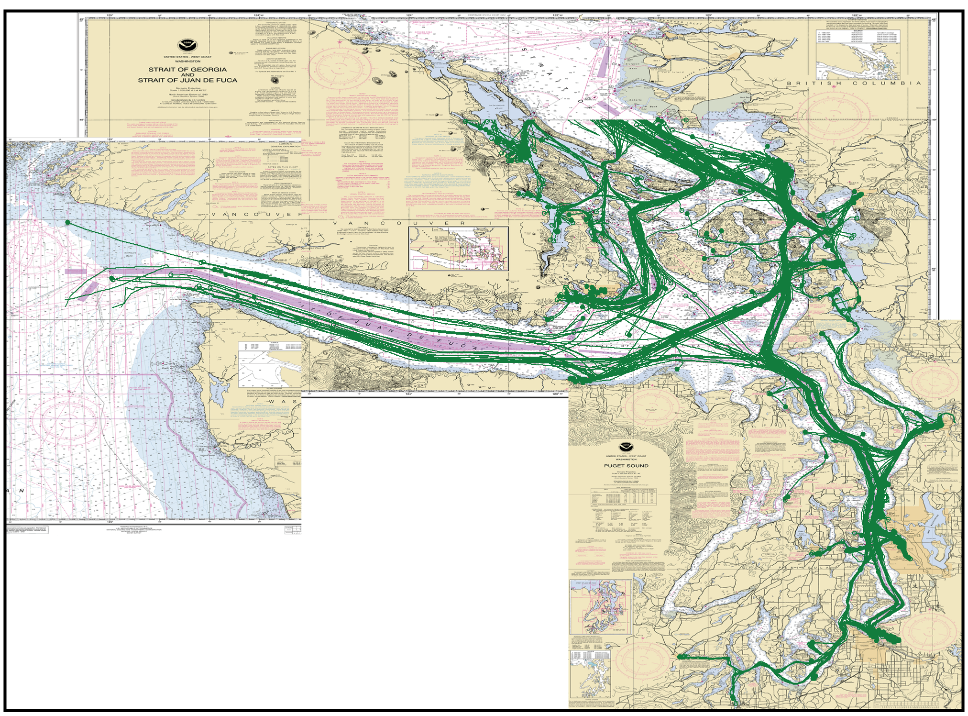


Figure C-10. Representative Routes Used by Tug Tow Barges.

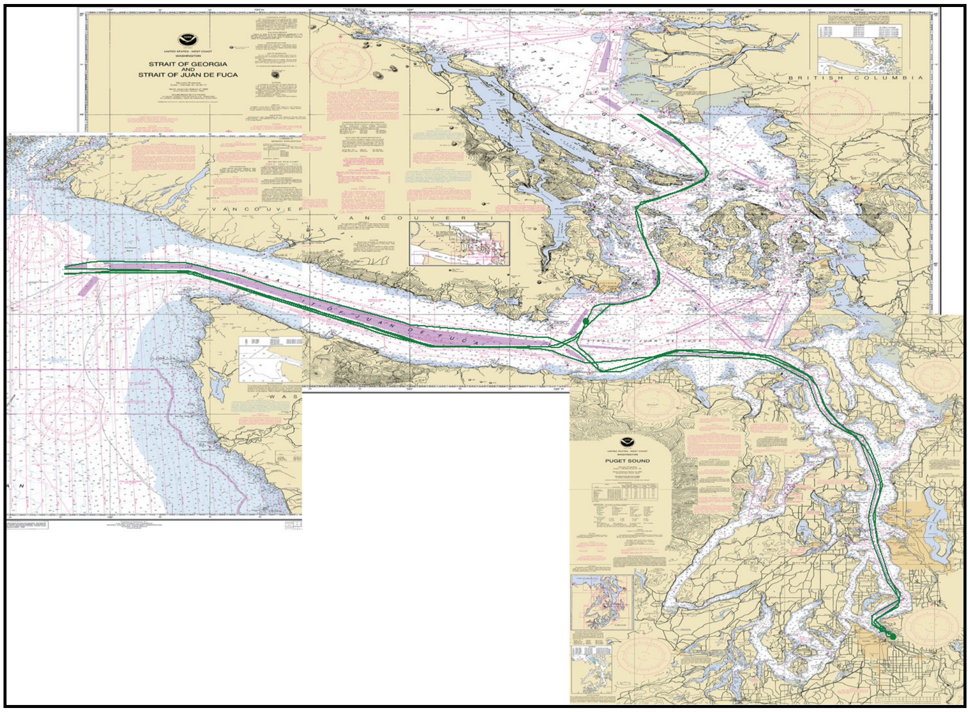


Figure C-11. Representative Routes Used by Vehicle Carriers.

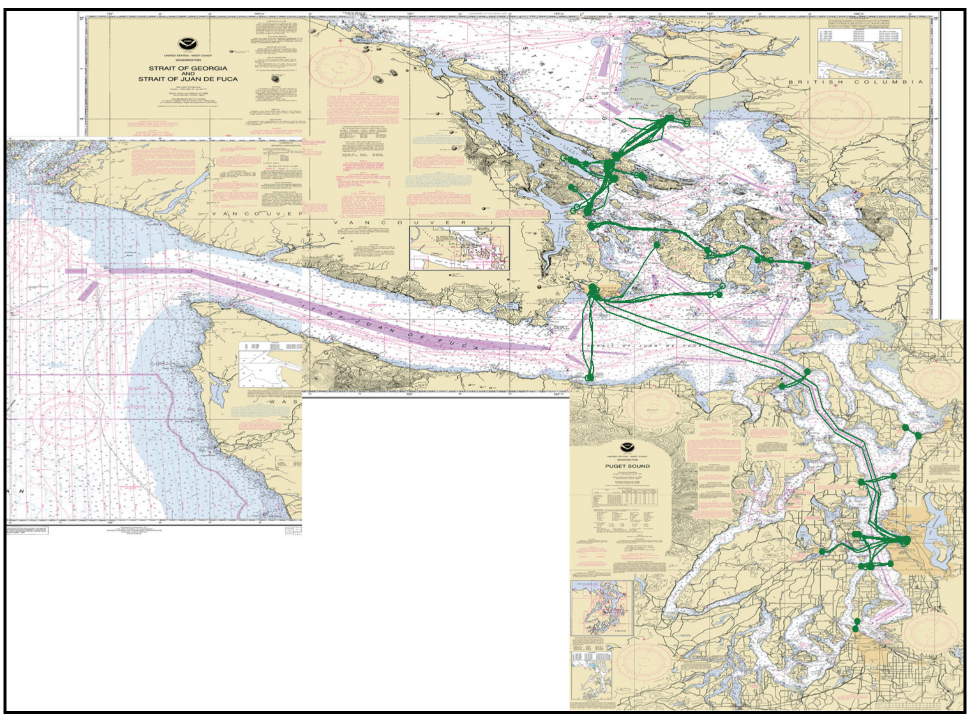


Figure C-12. Representative Routes Used by Ferries.

C-1.4. Vessel Dimensions

Table C-3 shows the vessel information used in the simulation for tankers, ATBs, and ITBs.

Table C-3. Tanker, ATB, and ITB type vessel information used in the simulation.

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
AEGEAN TRADER	Product	Tanker	SH	31374	8912	162.95	27.93	11.53
AKAMAS	Product	Tanker	DH	41448	9758	182.04	28.94	11.93
ALASKAN EXPLORER	Crude	Tanker	DH	193050	38826	286.85	50	18.8
ALASKAN FRONTIER	Crude	Tanker	DH	193050	38826	286.85	50	18.8
ALASKAN NAVIGATOR	Crude	Tanker	DH	193048	38826	286.85	50	18.8
ALIAKMON	Product	Tanker	DH	38858	11321	200	33.1	12.41
ANDES	Crude	Tanker	DH	68487	12446	200	33.1	12.41
ANGELICA SCHULTE	Crude	Tanker	DH	100036	16533	200	33.1	12.41
AP STAR	Product	Tanker	DB/SS	23876	8330	200	33.1	12.41
ARABIAN WIND	Product	Tanker	DB/SS	17482	7864	200	33.1	12.41
ASTRAL EXPRESS	Product	Tanker	DH	45770	9311	179.8	32.23	12.12
BARENTS WIND	Product	Tanker	DB/SS	22622	8237	179.8	32.23	12.12
BELSIZE PARK	Product	Tanker	DH	19937	8040	179.8	32.23	12.12
BOW CLIPPER	Product	Tanker	DH	37221	9393	179.8	32.23	12.12
BOW PRIMA	Product	Tanker	DH	46454	10207	179.8	32.23	12.12
BRIGHT PACIFIC	Product	Tanker	DH	46454	9306	179.8	32.23	12.12
BRITISH BEECH	Crude	Tanker	DH	106138	16521	240.5	42	14.88
BRITISH EXCELLENCE	Product	Tanker	DH	37333	9403	240.5	42	14.88
BRITISH HARRIER	Crude	Tanker	DH	120000	22890	179.9	32.23	12.8
BRITISH HAZEL	Crude	Tanker	DH	106085	16574	240.5	42	14.88
BRITISH LAUREL	Crude	Tanker	DH	106395	17507	240.5	42	14.88
BRITISH LOYALTY	Product	Tanker	DH	46803	9439	183.22	32.2	12.22
BRITISH OAK	Crude	Tanker	DH	106395	16159	240.5	42	14.88
BUM YOUNG	Product	Tanker	DH	19999	8045	240.5	42	14.88
BUNGA KANTAN DUA	Product	Tanker	DH	19774	8028	240.5	42	14.88
CABO HELLAS	Crude	Tanker	SH	69636	12576	240.5	42	14.88
CABO SOUNION	Crude	Tanker	DH	40038	13213	228	32.22	13.62
CAPE AVILA	Crude	Tanker	DH	105337	17341	228	32.22	13.62
CAPE BONNY	Crude	Tanker	DH	159152	28147	274.27	48	17.07
CAPTAIN H A DOWNING	Crude	Tanker	DH	39385	10820	207	27.43	11.19
CARIBBEAN SPIRIT	Product	Tanker	DH	46383	10201	207	27.43	11.19
CEDAR GALAXY	Product	Tanker	DH	19983	8043	207	27.43	11.19
CHAMPION ADRIATIC	Product	Tanker	DH	37658	9430	207	27.43	11.19
CHAMPION PACIFIC	Product	Tanker	DH	38465	9499	207	27.43	11.19
CHAMPION TRADER	Product	Tanker	SH	30990	8881	207	27.43	11.19
CHAMPION VENTURA	Product	Tanker	DB/SS	45574	10127	207	27.43	11.19
CHEMSTAR ACE	Product	Tanker	DH	19481	8007	207	27.43	11.19

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
CHEMTRANS SEA	Product	Tanker	DH	72365	12888	207	27.43	11.19
COASTAL RELIANCE	Product	ATB	DH	19000	7973	207	27.43	11.19
CSL ACADIAN	Product	Tanker	DH	37498	9417	207	27.43	11.19
DA YUAN HU	Crude	Tanker	DH	159149	26829	274	48.03	17.3
DAWN	Product	Tanker	DH	11668	7463	274	48.03	17.3
DENALI	Crude	Tanker	DB/SS	188000	36491	274	48.03	17.3
DESH GAURAV	Crude	Tanker	DH	113928	18735	274	48.03	17.3
ERIK SPIRIT	Crude	Tanker	DH	115525	19006	274	48.03	17.3
ETERNITY	Product	Tanker	DH	94993	15800	274	48.03	17.3
FAIRCHEM COLT	Product	Tanker	DH	19998	8045	274	48.03	17.3
FAIRCHEM GENESIS	Product	Tanker	DH	14281	7641	274	48.03	17.3
FAIRCHEM STALLION	Product	Tanker	DH	19947	8041	274	48.03	17.3
FAIRCHEM STEED	Product	Tanker	DH	19992	8044	274	48.03	17.3
FEDOR	Product	Tanker	DH	70156	12635	274	48.03	17.3
FJORD CHAMPION	Product	Tanker	SH	32477	9001	274	48.03	17.3
FORMOSA 15	Product	Tanker	DH	45400	10111	274	48.03	17.3
FRONT BRABANT	Crude	Tanker	DH	153320	21861	269.19	46	17.21
FRONT CLIMBER	Crude	Tanker	DH	149999	25921	269.19	46	17.21
FRONT SPLENDOUR	Crude	Tanker	DH	124999	21882	269	46	16.86
FRONT SYMPHONY	Crude	Tanker	DH	150500	22751	272	45.6	17.08
GINGA LION	Product	Tanker	DH	25441	8448	272	45.6	17.08
GINGA SAKER	Product	Tanker	SH	19996	8044	272	45.6	17.08
GUADALUPE	Product	Tanker	DH	47037	10261	272	45.6	17.08
GULF PROGRESS	Product	Tanker	DH	64959	13664	228.6	32.2	13.17
GULF SCANDIC	Crude	Tanker	DH	151459	26264	228.6	32.2	13.17
HEBEI MERCY	Product	Tanker	SH	10151	7362	228.6	32.2	13.17
HEBEI TREASURE	Crude	Tanker	SH	54158	10940	228.6	32.2	13.17
HELLESPONT TATINA	Crude	Tanker	DH	105535	17372	228.6	32.2	13.17
HELLESPONT TRINITY	Crude	Tanker	DH	148018	25463	228.6	32.2	13.17
HIGH CONSENSUS	Product	Tanker	DH	45800	8884	179.88	32.23	12.02
HIGH LIGHT	Crude	Tanker	DH	46843	10243	179.88	32.23	12.02
HOUSTON	Product	Tanker	DH	32689	9018	179.9	32.23	12.8
HUDSON	Crude	Tanker	DH	124999	20698	179.9	32.23	12.8
IASONAS	Crude	Tanker	DH	71500	12788	179.9	32.23	12.8
IKAROS	Crude	Tanker	DH	72828	12942	179.9	32.23	12.8
IONIAN TRADER	Product	Tanker	DH	39317	9572	179.9	32.23	12.8
IPANEMA	Crude	Tanker	DH	68781	12479	179.9	32.23	12.8
ISLAND MONARCH	Product	ATB	DH	8954	7283	179.9	32.23	12.8
ITB BALTIMORE	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
ITB GROTON	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
ITB NEW YORK	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
JAG LEELA	Crude	Tanker	DH	84999	14440	179.9	32.23	12.8
JILL JACOB	Crude	Tanker	DH	72909	12952	179.9	32.23	12.8

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
JOHN ERICSSON	Product	Tanker	DH	28256	8665	179.9	32.23	12.8
KENAI	Crude	Tanker	DH	123113	20350	179.9	32.23	12.8
KEYMAR	Crude	Tanker	SH	92017	15382	179.9	32.23	12.8
KODIAK	Crude	Tanker	DH	124822	24726	179.9	32.23	12.8
KOYAGI SPIRIT	Crude	Tanker	SH	95987	15941	182.5	32.2	12.67
KRITI CHAMPION	Product	Tanker	DB/SS	47618	10315	179.88	32.23	12.02
KUDU	Product	Tanker	DH	45948	8832	179.88	32.23	12.02
KYRIAKOULA	Crude	Tanker	DH	72354	12887	179.88	32.23	12.02
LAUREL GALAXY	Product	Tanker	DH	19805	8031	179.88	32.23	12.02
LEPTA MERMAID	Product	Tanker	DH	45908	10157	179.88	32.23	12.02
LETO PROVIDENCE	Crude	Tanker	DB/SS	49999	10538	179.88	32.23	12.02
LOUKAS I	Product	Tanker	DH	45557	10125	179.88	32.23	12.02
LUDOVICA	Product	Tanker	DH	47198	9276	182.5	32.2	12.67
MAPLE EXPRESS	Product	Tanker	DH	45798	10147	182.5	32.2	12.67
MARITIME MAISIE	Product	Tanker	DH	44404	10021	182.5	32.2	12.67
MERMAID EXPRESS	Product	Tanker	DH	45763	10144	182.5	32.2	12.67
ITB MOBILE	Product	ITB	DB/SS	48067	10357	179.9	32.23	12.8
MONTE LUNA	Product	Tanker	DB/SS	39742	9609	182.5	32.2	12.67
NEW AMITY	Crude	Tanker	DH	84999	14440	182.5	32.2	12.67
NEW ENDEAVOR	Product	Tanker	DB/SS	38960	9542	182.5	32.2	12.67
NEW HORIZON	Product	Tanker	SH	38891	9536	182.5	32.2	12.67
NORCA	Product	Tanker	DH	47094	10266	182.5	32.2	12.67
NORD SOUND	Product	Tanker	DH	45975	10163	182.5	32.2	12.67
NORD STRAIT	Product	Tanker	DH	45934	10160	182.5	32.2	12.67
NORTH CHALLENGE	Product	Tanker	DH	12181	7498	182.5	32.2	12.67
OCEAN RELIANCE	Product	ATB	DH	19000	7973	182.5	32.2	12.67
OS ARIADMAR	Product	Tanker	DH	46205	10185	182.5	32.2	12.67
OS CHICAGO	Crude	Tanker	DB/SS	92091	15392	182.5	32.2	12.67
OS PEARLMAR	Crude	Tanker	DH	69697	13153	182.5	32.2	12.67
OS POLYS	Crude	Tanker	DH	68623	12461	182.5	32.2	12.67
OS RUBYMAR	Crude	Tanker	DH	69599	12571	182.5	32.2	12.67
OS WASHINGTON	Crude	Tanker	DB/SS	91967	15375	182.5	32.2	12.67
OTTAWA	Product	Tanker	DH	70296	13907	228	32.23	13.8
PANAGIA LADY	Crude	Tanker	DH	46684	10229	228	32.2	13.62
PANAM ATLANTICO	Product	Tanker	DH	14003	7622	228	32.2	13.62
PAUL BUCK	Product	Tanker	DH	29500	8912	228	32.2	13.62
PECOS	Crude	Tanker	DH	157406	27708	228	32.2	13.62
PEDOULAS	Crude	Tanker	SH	96172	15968	228	32.2	13.62
PETRO VENUS	Crude	Tanker	SH	124999	20698	257.71	37.29	10.28
PLATINUM	Product	Tanker	DH	45614	10130	188.6	29.35	10.28
POLAR ADVENTURE	Crude	Tanker	DH	191460	31769	268.5	45	16
POLAR ALASKA	Crude	Tanker	DB/SS	191460	37645	286.93	43.94	10.28
POLAR CALIFORNIA	Crude	Tanker	DB/SS	191460	37645	286.93	43.94	10.28

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
POLAR DISCOVERY	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR ENDEAVOUR	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR RESOLUTION	Crude	Tanker	DH	141740	31769	268.5	45	16
POLAR TEXAS	Crude	Tanker	DB/SS	91393	15296	236.24	33.93	10.28
POTOMAC	Crude	Tanker	DH	159999	28362	274.63	40.79	10.28
PRINCE WILLIAM SOUND	Crude	Tanker	DH	122941	23525	247.5	40.8	15
PRINCESS NADIA	Crude	Tanker	DH	152328	26470	271.26	40.02	10.28
PUGET SOUND	Product	Tanker	DB/SS	27894	8637	154.89	27.58	10.28
REGINAMAR	Product	Tanker	DH	70313	13890	228	32.22	13.77
RICHARD G MATTHIESEN	Product	Tanker	DH	29526	8765	158.79	27.74	10.28
ROMOE MAERSK	Product	Tanker	DH	34807	9192	170.07	28.27	10.28
ROSETTA	Product	Tanker	DH	47037	9486	182.5	32.2	12.67
SABREWING	Product	Tanker	DH	49323	10474	193.96	29.72	10.28
SAMOTHRAKI	Crude	Tanker	DH	46538	10215	189.98	29.44	10.28
SAMUEL L COBB	Product	Tanker	DH	32572	23304	170.07	28.27	10.28
SANKO COMMANDER	Crude	Tanker	DH	71010	12732	218.94	31.89	10.28
SANKO CONFIDENCE	Crude	Tanker	DH	71010	12732	218.94	31.89	10.28
SANKO DYNASTY	Crude	Tanker	DH	106644	17546	246.82	35.46	10.28
SANKO QUALITY	Crude	Tanker	DH	95628	15890	239.35	34.35	10.28
SANMAR SERENADE	Product	Tanker	DH	45696	10138	188.73	29.36	10.28
SCF URAL	Crude	Tanker	DH	167931	23304	274.48	48	17.07
SEA RELIANCE ATB	Product	ATB	DH	19000	7973	128.57	26.69	10.28
SEABULK ARCTIC	Product	Tanker	DH	46094	10174	189.32	29.4	10.28
SEABULK PRIDE	Product	Tanker	DH	46094	10174	189.32	29.4	10.28
SEAMASTER	Crude	Tanker	DH	109266	17965	248.49	35.72	10.28
SICHEM PALACE	Product	Tanker	DH	8807	7274	75.86	25.67	10.28
SINGAPORE VOYAGER	Crude	Tanker	DH	105850	17421	246.31	35.38	10.28
SKIROPOULA	Crude	Tanker	DH	68232	12418	216.21	31.61	10.28
SKOPELOS	Crude	Tanker	DH	70146	12633	218.1	31.81	10.28
SMT CHEMICAL EXPLORER	Product	Tanker	DB/SS	34930	9202	170.31	28.28	10.28
SONANGOL GIRASSOL	Crude	Tanker	DH	159056	23313	274	48	17.02
SOUND RELIANCE ATB	Product	ATB	DH	19000	7973	128.57	26.69	10.28
SOUTH SEA	Crude	Tanker	DH	150000	25921	270.21	39.79	10.28
SPIRIT II	Crude	Tanker	SH	100336	16578	242.64	34.82	10.28
SR BAYTOWN	Crude	Tanker	DB/SS	59625	11492	206.96	30.75	10.28
SR COLUMBIA BAY	Crude	Tanker	DB/SS	124999	20698	257.71	37.29	10.28
SR HINCHINBROOK	Crude	Tanker	DB/SS	48869	10432	193.33	29.68	10.28
SR LONG BEACH	Crude	Tanker	SH	94999	15800	238.89	34.29	10.28
ST.GEORG	Product	Tanker	SH	5850	7083	47.82	25.38	10.28
STAVANGER VIKING	Crude	Tanker	DH	105400	17351	246.02	35.33	10.28
STENA COMMANDER	Crude	Tanker	DH	72290	12880	220.17	32.02	10.28
STENA COMPANION	Crude	Tanker	DH	72768	12935	220.62	32.07	10.28
STENA COMPATRIOT	Crude	Tanker	DH	72736	12931	220.59	32.06	10.28

Vessel Name	Cargo	Type	Hull	DWT	Displ.	Length	Beam	Draft
STENA CONSUL	Product	Tanker	DH	47171	10273	190.9	29.51	10.28
SWIFT FAIR	Crude	Tanker	DH	75469	13253	223.12	32.34	10.28
THEO T	Product	Tanker	DH	73021	12965	220.86	32.09	10.28
TIGER	Product	Tanker	DH	44987	10073	187.65	29.29	10.28
TORBEN SPIRIT	Crude	Tanker	DH	98600	16321	241.44	34.65	10.28
TROMSO RELIANCE	Crude	Tanker	DH	154970	20502	274	43.93	17.52
TURCHESE	Product	Tanker	DH	12000	7486	97.07	25.99	10.28
VOIDOMATIS	Product	Tanker	DH	61325	11669	208.89	30.92	10.28
WASHINGTON VOYAGER	Product	Tanker	DH	39167	9559	178.16	28.71	10.28
XANTHOS	Crude	Tanker	DH	61369	11674	208.94	30.93	10.28

Information about vessels that call at BP Cherry Point most frequently was provided by BP Shipping. Information for other tankers was obtained from a variety of online databases, including those of the classification societies, the Shipping Intelligence Network, and owners.

Information was not available from BP about the amount of crude or product each tanker, ATB, or ITB carried on each transit. Instead, the following assumptions were developed in conjunction with BP Shipping. For crude vessels, the tanker is assumed to be carrying 100% of its capacity when it arrives in the study area and 0% when it leaves the study area. However, some crude tankers call at multiple refineries in the visit to the study area. In this case, the tanker is assumed to offload equal amounts at each refinery. For product tankers, the vessels are assumed to leave the study area carrying 100% of its capacity and arrive empty. Transits between refineries in the study area are moving various products between them, and so are assumed to carrying 50% of its capacity. All vessels are assumed to be carrying 100% of their fuel capacity.

For other vessels, the US Coast Guard provided information on DWT, length, beam, and draft for as many vessels as were available in their VTS database. The Puget Sound Marine Exchange provided additional DWT and displacement data. The Washington State Ferries provided complete information on all their vessels. The vessels for which dimension information was complete were used to estimate relationships between the various dimensions for each type of vessel. These relationships were then used on the partial information for other vessels to estimate missing information. For vessels with no information, an average for that vessel type was used. Again, all vessels are assumed to be carrying 100% of their fuel capacity.

C-2. Fishing Seasons Modeling

C-2.1. US, Canadian, and tribal fishing data

Three primary commercial fishery vessel fleets are identified: State Commercial fisheries, Tribal Commercial Fisheries, Canadian Commercial Fisheries. Each is further delineated below.

C-2.1.1. State Commercial Fisheries

State Commercial Fisheries include all commercial fisheries that are wholly regulated by the Washington Department of Fish and Wildlife (WDF&W). The state commercial fishery fleet incorporates a diverse body of vessel types operating in U.S. regions of the VTRA study area. The WDF&W was contacted in October 2006 to initiate a conversation pertaining to modeling the movement of this fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area (see Systems Description) was utilized to determine the segments of the commercial fishing fleet that would be considered for further investigation. These were identified using the species and gear-type:

- Salmon-Seine
- Salmon-Gillnet
- Shrimp-Pod
- Crab-Pod

In order to approximate the movement of the commercial fisheries fleet, the WDF&W fisheries manager for the species and gear-type were contacted individual. Each was elicited for data pertaining to typified movements of the commercial fishery fleet over which the manager had regulatory authority. Through an iterative process, wherein data was elicited, compiled and returned, a series of rules were established that would allow each fleet to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type

- regulatory boundaries of fishery
- regulatory times of fishery
    - time of year (months)
    - time of day (day light, clock, 24 hour)
- typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
    - time of day
- number and type of vessel participating in fishery
    - number of vessel participating as a function stage of fishery
        - first third
        - second third
        - final third
    - typified design of participating vessel
        - length
        - draft
        - fuel capacity
        - speed

The WDF&W fisheries managers offering this information were long term WDF&W employees with a body of in-office and on-water managerial experience that would allow them to offer insight to specific and general habits of the commercial fishing fleet and commercial fishers. The quality and quantity of data gathered during this iterative process ranged from allegorical (based on 20-years experience in managing fishery), to the purely quantitative (based on documented catch records of locations, dates, times and ports of call).

C-2.1.2. Tribal Commercial Fisheries

Tribal Commercial Fisheries include all commercial fisheries that are regulated by individual sovereign tribal authorities. The tribal commercial fishery fleet incorporates a diverse body of vessel types operating in U.S. regions of the VTRA study area, and an equally diverse body of tribal regulatory authorities. This data gathering process specifically focused on fisheries that utilize vessels under 20 meters in registered length. Vessels over 20 meters are expected to be captured as active or passive participants in the Puget Sound Vessel Traffic System.

The Northwest Indian Fisheries Commission was contacted in October 2006 to initiate a conversation pertaining to modeling the movement of the tribal commercial fisheries fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area was utilized to determine the tribal organization that would be considered for further investigation. These were identified as:

- Lummi Nation
- Makah Tribe
- Nooksack Tribe
- Suquamish Tribe
- Tulalip Tribe
- Puyallup Tribe
- Suquamish Tribe
- Muckleshoot Tribe
- Squaxin Island Tribe
- Point-No-Point Tribal Council

Each of these tribal organizations was contacted independently in an effort to elicit information pertaining to the commercial fishing fleet over which each tribal organization had regulatory authority. Participation of each tribal organization was wholly up to the discretion of the tribal organization contacted. For those organizations that chose to participate, a person with specific knowledge of the commercial fisheries activities was contacted for the purpose of approximating the movement of the commercial fishing fleet for a representative year. In the context of all tribal organizations, the fisheries considered are (by species and gear-type):

- Salmon-Seine
- Salmon-Gillnet
- Crab-Pod
- Shrimp-Pod

- Halibut-Longline

Not all tribal organizations have 'Usual and Accustom" rights to each of these fisheries. For those fisheries that each participating tribal organization does participate, a competent authority was requested to supply information that would approximate typified movements of the fishery fleet. Through an iterative process, wherein data was elicited, compiled and returned, a series of rules were established that would allow each fleet to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type
  - regulatory boundaries of fishery
  - regulatory times of fishery
    - time of year (months)
    - time of day (day light, clock, 24 hour)
  - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
    - time of day
    - route of transit
  - number and type of vessel participating in fishery
    - number of vessel participating as a function stage of fishery
      - first third
      - second third
      - final third
    - typified design of participating vessel
      - length
      - draft
      - fuel capacity
      - speed

The tribal organizations' fisheries managers generally had long-term managerial experience, as well as significant experience as commercial fishers, that would allow them to speak authoritatively as to the specific and general habits of the commercial fishing fleet and commercial fishers. The quality and quantity of data gathered during this iterative process ranged from allegorical (based on 20-years experience in managing fishery), to the purely quantitative (based on documented catch records of locations, dates, times and ports of call).

C-2.1.3. Canadian Commercial Fisheries

The Canadian commercial fishers are not delineated as Tribal (termed First Nations) and non-tribal fisheries. This is because the Canadian Department of Fisheries and Oceans (DFO) holds regulatory authority over both user groups, thus the DFO fishery managers are the singular competent authority for all commercial fisheries.

The Canadian commercial fishery fleet incorporates a diverse body of vessel types operating in the Canadian regions of the VTRA study area. The DFO was contacted in October 2007 to initiate a conversation pertaining to modeling the movement of this fleet for a representative year (2005). During this initial conversation, the defined VTRA Study Area (see Systems Description) was utilized to determine the segments of the commercial fishing fleet that would be considered for further investigation. These were identified by species and gear-type:

- Salmon-Seine
- Salmon-Gillnet
- Shrimp-Pod
- Crab-Pod

The competent managerial authority for all Canadian Commercial fisheries in the VTRA Study Area is housed in the Victoria office of the DFO. This office was contacted and elicited for data pertaining to typified movements of the commercial fishery fleet over which the manager had regulatory authority. An initial meeting took place in December 2007. This initial meeting began an iterative process through which data was elicited, compiled and returned in order to develop a series of rules that would allow typified fleet movements to be modeled for a representative year. These rules are listed below:

- For each fishery and gear type
    - regulatory boundaries of fishery
    - regulatory times of fishery

        - time of year (months)
        - time of day (day light, clock, 24 hour)
    - typical distribution of fleet across regulatory area
    - typical transit habits of fishers between fishing grounds and home-port or intra-fishery port of call (to deliver days/weeks catch)
        - time of day of transits
    - number and type of vessel participating in fishery
        - number of vessel participating as a function stage of fishery
            - first third
            - second third
            - final third
        - typified design of participating vessel
            - length
            - draft
            - fuel capacity
            - speed

The DFO fisheries managers participating in this process were long-term DFO employees, with a body of in-office and on-water managerial experience that would allow them to offer insight to specific and general habits of the commercial fishing fleet and commercial fishers.

C-2.2. Creating fishing transits in the simulation

In the simulation, the number of fishing vessels leaving each port on a given day was determined from the data provided by the various organizations. The data was also used to determine where they would fish and what patterns of movement they would follow based on the type of fishing. The length of time that the vessel would fish before returning to port was also determined from the data provided.

The first step in modeling fishing traffic is to define the areas in which different types of fishing occurs. Maps of the fishing areas were provided by the various experts and organizations contacted. For each fishing area, a grid of cells was defined over the map of the study area in the simulation. These cells could then be clicked to identify them as part of a given fishing area. The maps of the fishing areas provided were then transcribed in to the simulation by clicking the areas on the grid to match the maps. The next step in modeling fishing traffic was to define the routes used to get from the fishing vessels home port to the fishing area and back again. These routes were clicked in to the simulation and verified with experts in fishing in the area.

With the routes and fishing areas defined, we could then determine when and how many fishing vessels to add to the simulation. Table C-4 shows the information derived from the various organizations. The table shows the various types of fishing. SC and TC indicate State Commercial and Tribal Commercial respectively. The dates within which each type of fishing occurs are also shown, along with the time of day that a fishing vessel would leave and the length of time that a vessel would fish for. Also determined, but not shown in the table, were the probability that vessels would leave on any given day of the week and the number of vessels that would leave from each home port if fishing did occur on that day. Thus in the simulation, it was first determined if a given type of fishing would occur on that day and then each vessel would determine which fishing area it would go to. Given the home port and the fishing area, the vessel would follow a prescribed route to the fishing area, fish for the specified length of time, and then return on the same route to the home port.

Fishing vessels will behave differently depending on what type of fishing they are involved in. A gillnet requires that the vessel drift with the current, while a seine net is pulled slowly behind the vessel. On arrival in a fishing area, the vessels were made to move mostly in a straight line, but with a random deviation to mimic their search for fish. They would then follow their prescribed fishing movement, either drifting or slowly trolling. Shrimp pods and crab pots are dropped at chosen locations and later picked up, so this motion was also mimicked. Vessels moving close to the edge of a fishing area would turn to one side or the other to remain in the defined fishing area. Thus the movements of each vessel were designed to mimic as closely as possible their actual movements and not just travel at speed in straight lines and bounce like a billiard ball at the edge of the area as has been used in other maritime simulation models.

Table C-4. The fishing vessel arrival information fed in to the simulation.

Catch	Fleet	Net Type	Begin Date	End Date	Start Time	Duration
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	7/20	8/20	7:00 AM	0.5
Salmon	SC	Gillnet	8/21	9/28	7:00 AM	0.5
Salmon	SC	Gillnet	9/29	10/17	7:00 AM	0.5
Salmon	SC	Gillnet	10/18	11/30	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	SC	Seine	8/21	9/28	7:00 AM	0.5
Salmon	SC	Seine	9/29	10/17	7:00 AM	0.5
Salmon	SC	Seine	10/18	11/30	7:00 AM	0.5
Salmon	TC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	TC	Seine	7/20	8/20	7:00 AM	0.5
Salmon	TC	Gillnet	7/20	11/15	7:00 AM	0.5
Shrimp	SC	na	5/1	5/1	7:00 AM	0.5
Shrimp	SC	na	5/2	9/30	7:00 AM	0.5
Shrimp	TC	na	4/1	5/31	7:00 AM	0.5
Shrimp	SC	na	5/1	5/1	7:00 AM	0.5
Shrimp	SC	na	5/2	9/30	7:00 AM	0.5
Shrimp	TC	na	4/1	5/31	7:00 AM	0.5
Salmon	SC	Gillnet	10/1	10/15	7:00 AM	0.5
Salmon	SC	Gillnet	10/16	11/30	7:00 AM	0.5
Salmon	SC	Seine	10/16	11/30	7:00 AM	0.5
Shrimp	SC	Trawl	5/1	9/30	7:00 AM	5
Shrimp	SC	Pod	5/1	9/30	7:00 AM	2.5
Crab	SC	Pod	3/1	2/28	7:00 AM	3.5
Salmon	TC	Makah Dragger - A	3/1	2/28	7:00 AM	0.5
Salmon	TC	Makah Dragger - B	7/16	10/15	7:00 AM	0.5
Salmon	TC	Makah Troll - A	5/1	9/30	7:00 AM	1
Salmon	TC	Makah Troll - B	10/1	2/28	7:00 AM	1
Salmon	TC	Makah Gillnet	7/15	8/31	7:00 AM	0.5
Salmon	TC	Makah Gillnet	9/1	11/30	7:00 AM	0.5
Crab	SC	Pots	10/1	10/31	7:00 AM	1
Crab	SC	Pots	11/1	11/30	7:00 AM	1
Crab	SC	Pots	12/1	12/31	7:00 AM	1
Crab	SC	Pots	1/1	1/31	7:00 AM	1
Crab	SC	Pots	2/1	2/28	7:00 AM	1
Crab	SC	Pots	3/1	3/31	7:00 AM	1

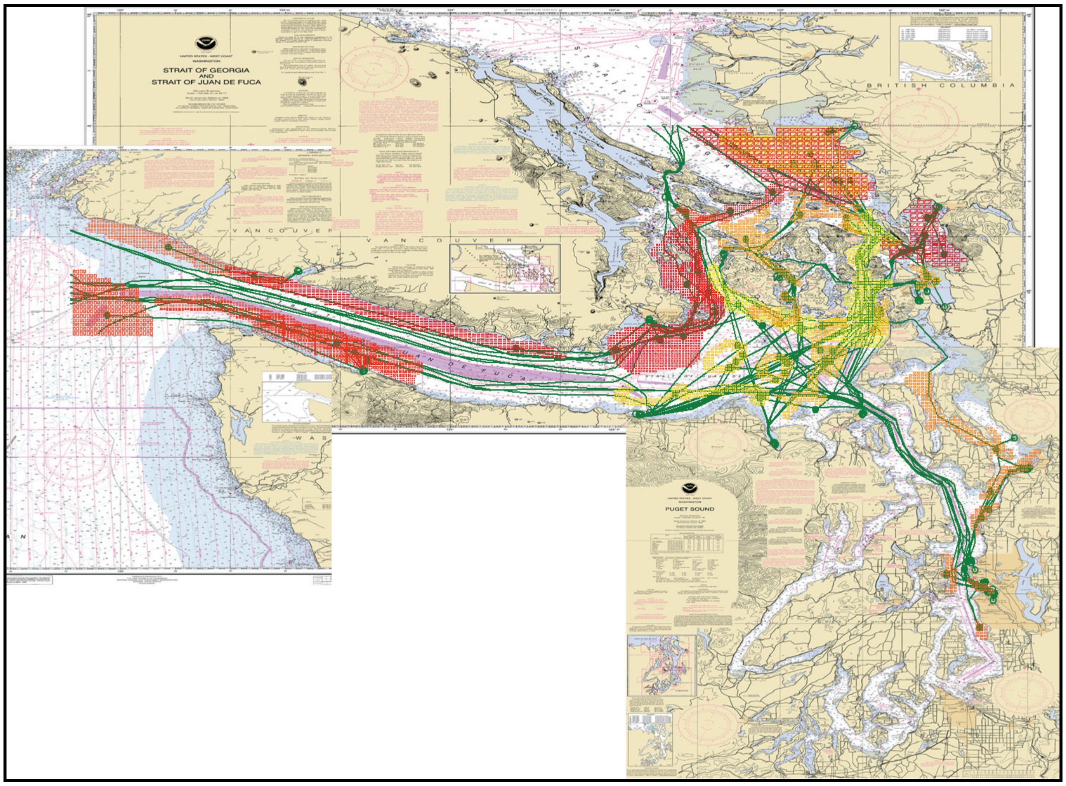


Figure C-13. Fishing areas and representative routes used by fishing vessels.

C-2.3. Routes and fishing areas used in the simulation

The fishing areas and routes used by fishing vessels in the simulation are shown in Figure C-13.

C-3. Regatta Modeling

C-3.1. US regatta data

Permitted non-commercial traffic is all traffic that does not actively participate in a commercial venture (commercial fishing or whale watching), but that does answer to some regulatory authority through a permitting process. Included in Figure 1 are:

- Sailing regattas
- Vessel parades
- Sport fishing competitions
- Powerboat races.

The primary driver to non-commercial permitted traffic being delineated in this manner is the US Coast Guard Permitting process, which has specific categories the person or organization seeking a permitted is required to complete. During the permitting process the permitted is required to submit the additional information below:

- Date of event
- Start time and end time of event
- Type of event
- Number of vessels involved in event
- Starting location of event
- Ending location of event

With data at this detail, the VTRA can incorporate permitted non-commercial traffic as a separate fleet of vessels operating in the VTRA study area.

C-3.2. Creating yacht transits in the simulation

The Coast Guard data indicates the location of each event, the date and time, the type of event, and the number of vessels involved. A sample of the data is shown in Table C-5. For each event, a route was added to the simulation. Events that occurred in areas outside the main waterways in the study area were not included as they could not affect the risk measures of interest. At the appropriate time, the specified number of vessels is added on the representative route. All vessels in the event will not travel at the same speed and they will not travel on exactly the same route. Thus each vessel was given a speed that followed a probability distribution for that type of vessel, making some vessels pull ahead and others fall behind. Each vessel was also given a random dither from the route. In this manner, each regatta event was represented in the simulation.

C-3.3. Regatta routes used in the simulation

Figure C-14 shows the routes used in the simulation for the regattas.

Table C-5. A sample of the regatta records from the US Coast Guard.

Event Location	Event Type	Date and Time	Nos. of Boats
Des Moines around Blakely Rock and return	Sailboat Race	1/7/05 12:00 PM	100
Commencement Bay	Sailboat Race	1/14/05 8:00 AM	40
Blakely Rocks to Point Jefferson	Sailboat Race	1/14/05 12:00 PM	25
Des Moines around Blake Island and return	Sailboat Race	1/14/05 12:00 PM	10
Edmonds to Alki	Sailboat Race	1/14/05 12:00 PM	25
Commencement Bay	Sailboat Race	1/21/05 8:00 AM	40
Everett	Sailboat Race	1/22/05 12:00 PM	25
Everett	Sailboat Race	1/29/05 12:00 PM	25
Commencement Bay	Sailboat Race	2/4/05 8:00 AM	40
Blakely Rocks to Point Jefferson	Sailboat Race	2/11/05 12:00 PM	25
Des Moines around Vashon Island and return	Sailboat Race	2/11/05 12:00 PM	10
Edmonds to Alki	Sailboat Race	2/11/05 12:00 PM	25
Everett	Sailboat Race	2/12/05 12:00 PM	25
Olympia Shoal around Anderson Island and Return	Sailboat Race	2/18/05 12:00 PM	100
Commencement Bay	Sailboat Race	2/25/05 8:00 AM	40
Everett	Sailboat Race	2/26/05 12:00 PM	25
Commencement Bay	Sailboat Race	3/4/05 8:00 AM	40
Commencement Bay	Sailboat Race	3/11/05 8:00 AM	40
Everett	Sailboat Race	3/12/05 12:00 PM	25
Blakely Rocks to Point Jefferson	Sailboat Race	3/18/05 12:00 PM	25
Edmonds to Alki	Sailboat Race	3/18/05 12:00 PM	25
Gig Harbor to Blake Island	Sailboat Race	3/18/05 12:00 PM	90
Commencement Bay	Sailboat Race	3/25/05 8:00 AM	40
Everett	Sailboat Race	3/25/05 12:00 PM	25
Budd Inlet	Sailboat Race	4/1/05 11:30 AM	40
Budd Inlet	Sailboat Race	4/2/05 11:30 AM	40

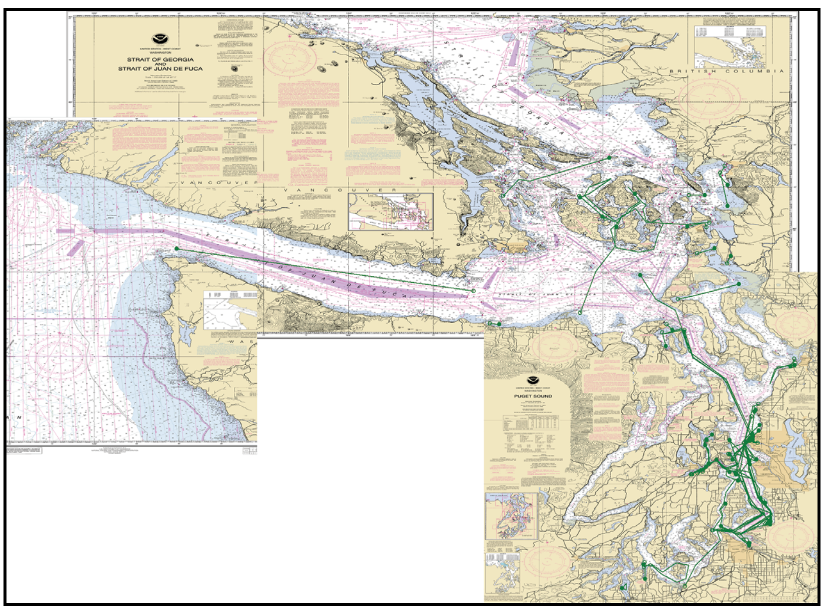


Figure C-14. Representative Routes Used by USCG Registered Yacht Regattas.

C-4. Whale Watcher Modeling

C-4.1. The Sound Watch records of interaction with whales

There is a robust commercial whale watching industry that typically operates in the region of the San Juan Islands Archipelago. Commercial whale watching vessels that participate on a daily bases can number in the hundreds at the height of the summer season, with vessels transiting the waters of Straits of Georgia, Rosario Strait, Haro Strait, Boundary Pass and Juan de Fuca-East as J and K pods of Orca Whales migrate the region. The US/Canadian international boundary is typically transparent to the commercial whale watching vessels that transit from near all port cities in the region, with US and Canadian fleets freely mixing in all locations during whale watching activities.

Unlike the commercial fisheries, there is no specific US or Canadian government competent regulatory authority with the body of knowledge that would allow the commercial whale watching fleet to be modeled. Therefore, raw data pertaining to the commercial whale watching fleet was obtained through a publicly accessible database developed and maintained Sound Watch (as part of The Whale Museum).

Sound Watch is a privately funded boater education program, with no regulatory authority over the commercial whale watching fleet. However, the intent and purpose of Sound Watch is to observe and document the activities of the whale watching fleet (commercial or private). This documentation process includes capturing specific data pertaining to:

- the number of vessels within a 2-mile radii of the whale-pod at every half hour
- the home port of vessels commonly seen within the 2-mile radii of the whale pod
- the location of the whale pod documented every half hour as Latitude and Longitude.

This data was made available packaged as the Orca Watch database. The Orca Watch database allowed the typical size and movement of the whale watching fleet to be reasonably approximated and included in the simulation.

C-4.2. Creating whale watching transits in the simulation

The movements of whale watching vessels are determined by the movements of the orca pods. The Sound Watch data gives the location of the orcas and then the number of vessels within a 2 mile radius of them. Removing the types of vessels that we have already modeled, we could move the orcas in the simulation and then add a swarm whale watching vessels around them. The number of vessels in the swarm is varied over time according to the counts in the Sound Watch data.

Each record in the Orca database consists of the date and time of the observation, the location of the orcas (actually the Sound Watch vessel), and the number of various types of vessels in a 2 mile radius around them. The number of vessels varies over the day as some vessels leave port early and some later and vessels have different lengths of trips. While it is known how many commercial whale watching vessels come from each port, it is not known which ones are present on any given day or at any given time. Thus it was not possible to model the transit from port to the orcas' location and back. Instead, successive records on a given day are used to determine a route for the orcas to follow and a speed (based on the distance and time between observations). The orcas are then moved along a straight line at the calculated speed. We then know the number of vessels that were observed near the orcas and so we add the specified number of vessels randomly dithered within a 2 mile radius of the orcas at any given time. These vessels move with the orcas in a straight line and at the calculated speed.

C-4.3. Routes used in the simulation

The movements recorded in the Orca database are shown in Figure C-15.

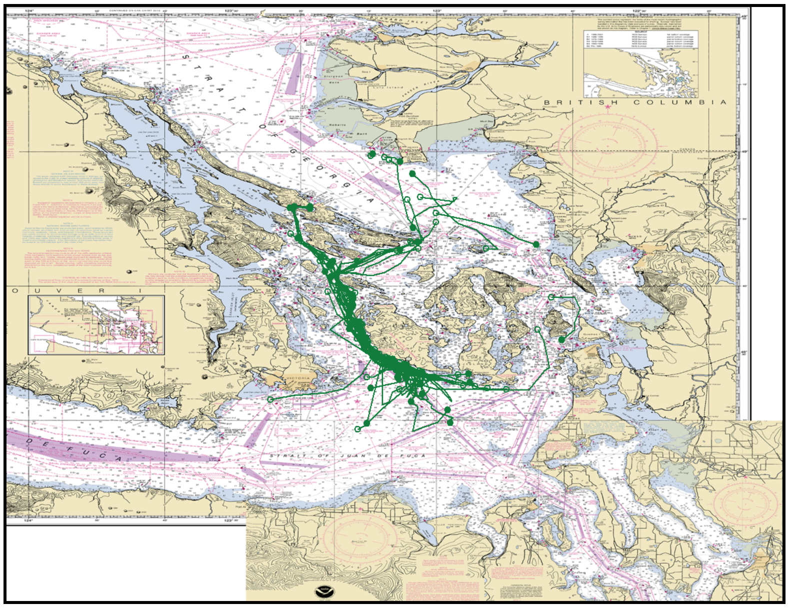


Figure C-15. Routes of whale watching movements record by Sound Watch.

C-5. Traffic Rules

C-5.1. Regulations used

Reporting to the VTS is not the only requirement for vessels transiting the region. There are restrictions on where a vessel may transit, called traffic separation schemes, restrictions on speed, one-way zones, specified anchorage areas, escorting rules for oil tankers, and pilotage requirements.

Each of the charts showing representative routes also includes pink areas along certain waterways. These depict traffic separation schemes for vessels over 20 meters in length, or regions in which vessels should not travel, keeping vessels transiting in opposite directions separated from each other. Areas of convergence of traffic are also depicted and caution is required in these areas. Vessels crossing the separation scheme must do so as close to a right angle as possible. No fishing or anchoring is allowed in the separation scheme area and vessels smaller than 20 meters and sailing vessels are not allowed to impede vessels in the scheme. Vessels not participating in the scheme or crossing the scheme must stay away from the areas depicted. There are also speed restrictions in various areas. In Elliot Bay, vessels are restricted to 5 knots; in Rosario Strait, deep draft vessels are restricted to 12 knots; and in the Saddlebags and Guemes Channel area, vessels are restricted to 6 knots.

The US Coast Guard has also designated a special navigation zone in Rosario Strait. This means that a vessel longer than 100 meters or more than 40,000 DWTs cannot meet, overtake, or cross within 2,000 yards of another vessel that meets these size limits within Rosario Strait. Also towing vessels cannot impede the passage of vessels more than 40,000 DWTs in this area. A similar designation is made in Haro Strait, but just applies to the smaller area at Turn Point, not the whole of Haro Strait. Guemes Channel and the area around Saddlebags and Vendovi Island are also areas where it is difficult for two vessels over 40,000 DWTs to maneuver around each other. While the area is not specifically designated as a special navigation zone, the Puget Sound VTS operates the area as if it were to avoid dangerous situations. Thus the Rosario Strait rules are essentially extended to include the waters east of Rosario Strait in practice.

Vessels requiring anchorage must get approval from the relevant VTS. There are many designated anchorage areas in the region, but four are specifically relevant to this study. Firstly, there is a large general anchorage area at Port Angeles for all deep draft vessels. There are then three anchorages with more limited capacity. Cherry Point anchorage is a short-term anchorage for tankers waiting to dock at Cherry Point or Ferndale. Anchorages around Vendovi Island can be used for longer; there are three designated anchorages for deep draft vessels and two for tugs. Finally, there are four anchorages at Anacortes, with one specifically designated for lightering operations.

The Puget Sound Pilots provide pilotage service for all U.S. ports and places East of 123 degrees 24' W longitude in the Strait of Juan de Fuca, including Puget Sound and adjacent inland waters. Pilotage is compulsory for all vessels except those under enrollment or engaged exclusively in the coasting trade on the west coast of the continental United States (including Alaska) and/or British Columbia. The pilot station is at Port Angeles, meaning that vessels picking up or dropping off a pilot will pass by Port Angeles at a slow speed, allowing a pilot boat to pull aside and the pilot to board or disembark on a pilot ladder. The pilots will navigate vessels to the dock and then back to the Port Angeles on their outbound trip.

Vessels transporting crude oil or petroleum products that are over 40,000 DWTs are required to have a tug escort beyond a point east of a line between Discovery Island and New Dungeness Light.

C-5.2. Implementing traffic rules in the simulation

While these rules are easy for a person to follow, we must be much more literal and specific in the simulation. Let us consider a tanker passing Buoy J and heading for BP Cherry Point. Figure C-16 shows the locations of interest in the implementation of the traffic rules in the simulation. The tanker will follow its representative route through the Straits of Juan de Fuca at sea speed, specifically 16 knots. At Port Angeles it must pick up a Puget Sound pilot from the pilot boat. In the simulation, the tanker will slow to 10 knots as it approaches Port Angeles and then to 6 knots when it nears the pick up area, before returning to 10 knots.

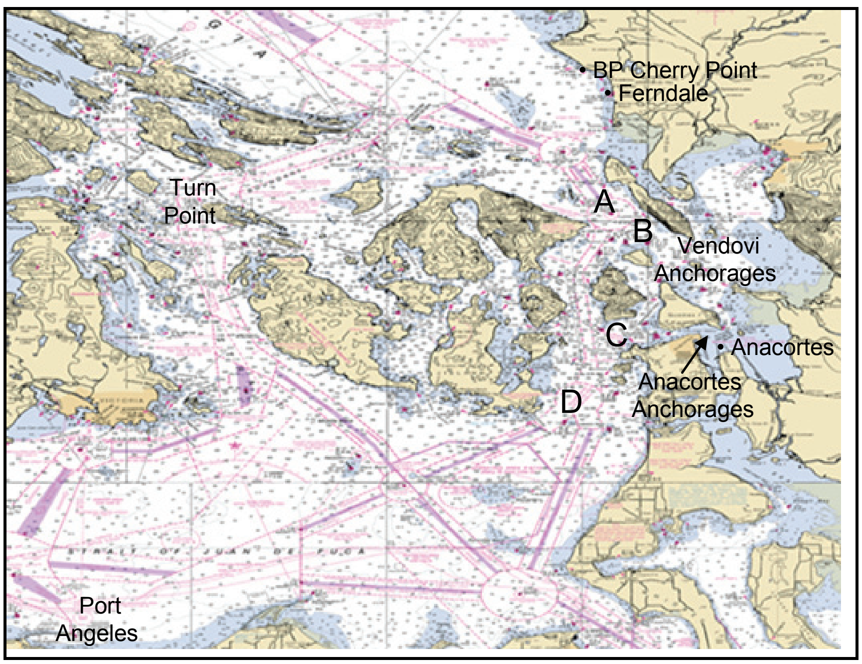


Figure C-16. The locations involved in implementing the traffic rules.

However, as the tanker continues from Port Angeles, we must now figure out when it can pass through the one-way zone at Rosario Strait. In the simulation, we find the vessel that will pass through the one-way zone ahead of the tanker, if any, and what time it is scheduled to arrive at the beginning of the one-way zone. We must then consider the directions through Rosario of the two vessels. The tanker will enter the one-way zone at point D shown in Figure C-16 and wishes to transit to point A. If the other vessel, is entering at points B, C, or D, and leaving at point A, then the tanker can follow it while maintaining the required 2,000 yard separation. We then calculate the time that the tanker can arrive at point D and slow the vessel, if need be, as it approaches to make sure it does not get there before its scheduled time. However, if the other vessel is leaving Rosario at point D or even entering at A and leaving at B or C, then the two vessels are heading for each other and the tanker must not reach point A until the other vessel is clear. We then calculate the time it will take the vessel to reach its exit point and the time that it will take the tanker to reach that point and slow the tanker to ensure that there will not be a conflict. Interviews with both Puget Sound Pilots and tanker masters from BP Shipping and ATC informed us that the vessels will not actually pass at the boundary of the one-way zone, but instead they leave room for error and pass beyond the one-way zone. Thus our calculations had to include this room for error as well. Thus we calculate the time it will take the other vessel to pass a safe distance beyond its exit point.

Using these calculations, we can now find the appropriate speed for the vessel to transit between Port Angeles and point D. If this speed falls below 5 knots, then tanker can remain at anchorage at Port Angeles, but this is rare. Through Rosario Strait, the maximum speed for the tanker is 10 knots, but if it is following another vessel then it must slow to maintain the required separation.

Once the tanker reaches a point east of a line between Discovery Island and New Dungeness Light then the simulation must check if an escort tug is needed. If the tanker is over 40,000 DWT and if it is carrying crude or product then an escort tug is added to the simulation, following behind the tanker until it arrives at dock or anchorage.

At the same time as considering the one-way zone, the tanker must also consider whether a dock is available at BP Cherry Point. Crude tankers must check if the south wing is available. Product tankers will check the north wing first (if we are running a case that includes the north wing) and then check the south wing if the north wing is not available. If a dock is not available, then there are various options.

The first choice is anchoring at the Cherry Point anchorage, which is actually just south of Ferndale in the current anchorage configuration. However, this anchorage is for short term stays, so the tanker will only use this anchorage if there is no other vessel here and a dock will become available within 12 hours. If using the Cherry Point anchorage, then the tanker will anchor here until a dock becomes available and then it will proceed to that dock.

If not using Cherry Point anchorage, then the next option is the anchorages near Vendovi Island. There are three anchorages at Vendovi. If the tanker is going to anchor at Vendovi to await a dock, then it will proceed through Rosario Strait and exit at point B and proceed to its anchorage. If other vessels are intending to leave an anchorage at Vendovi, then they will have to wait, as they cannot pass either in Rosario because of the one-way zone or between point B and the anchorage due to the effective one-way zone here.

If the Vendovi anchorages are not available, then the tanker may use the Anacortes anchorages. There are four anchorages at Anacortes. If the tanker is going to anchor at Anacortes to await a dock, then it will proceed through Rosario Strait and exit at point C and proceed to its anchorage. If other vessels are waiting to leave an anchorage at Anacortes or docks at Anacortes, then they will have to wait as they cannot pass either in Rosario because of the one-way zone or between point C and the anchorage due to the effective one-way zone here. The final option, if all possible anchorages are not available, then the tanker may anchor at Port Angeles.

Once the tanker arrives at BP Cherry Point, the relevant dock is recorded as unavailable and the time that the vessel stays at dock for loading or unloading is found from the VTOSS transit data. Two hours before the end of this time, if the tanker is scheduled to pass through Rosario again, then the simulation once again checks when the last vessel is scheduled to arrive through Rosario. The time that the tanker can arrive at point A is then calculated by considering the last vessels direction through Rosario as before for the inbound vessel. If the vessel will be delayed by more than 4 hours waiting for the one-way zone to open up, then the pilot and master will consider using a route through Haro Strait if they are heading to Port Angeles or out to sea. Some pilots and masters will choose to use Haro Strait, while others will choose to wait. Thus we use a 50% chance in the simulation that Haro Strait will be used, as developed through interviews with both pilots and tanker masters. Again an escort tug will transit with the tanker if it is over 40,000 DWT and carrying crude or product until the tanker passes a point east of a line between Discovery Island and New Dungeness Light or it reaches its destination.

C-6. Modeling weather and current within the VTRA Simulation

At a minimum the objective of the environmental modeling in the VTRA simulation should achieve a refinement similar to that of the locations definitions as displayed in Figure C-17. This location refinement is used in the expert judgment elicitation questionnaires and a weather modeling refinement at that level of detail ensures a seamless integration of the accident probability analysis model layer with the exposure analysis layer. The annual accident frequency analysis layer uses as input the incident-accident database analysis (Appendix A), the expert judgment (Appendix D), and the frequency of various scenarios occurring within the VTRA simulation (i.e. the exposure analysis).

At the outset of the project we commenced with the modeling of the dynamics of current, wind (in terms of wind speed and wind direction) and visibility. At that time little was know about the availability of traffic data for the modeling of traffic routes and traffic dynamics and we set out to produce a weather simulation for the years 2002-2005. As it turned out, due to VTOS traffic data availability at a certain level of detail we were able to model a traffic picture for the year 2005. The available VTOS data for 2005 allowed us to "replay" vessel traffic movements on a set of representative constructed routes. The previous sections have discussed this process in more detail. We shall discuss in the following sections the current model, the wind modeling and finally the visibility model as implemented within the VTRA simulation.

C-6.1. Current Modeling

A total of 130 current stations in the VTRA Study area were modeled within the VTRA study area. The primary data sources to model current were the WXTIDE software by Michael Hopper, the NOAA tides and current web-site and the MAPTECH software.

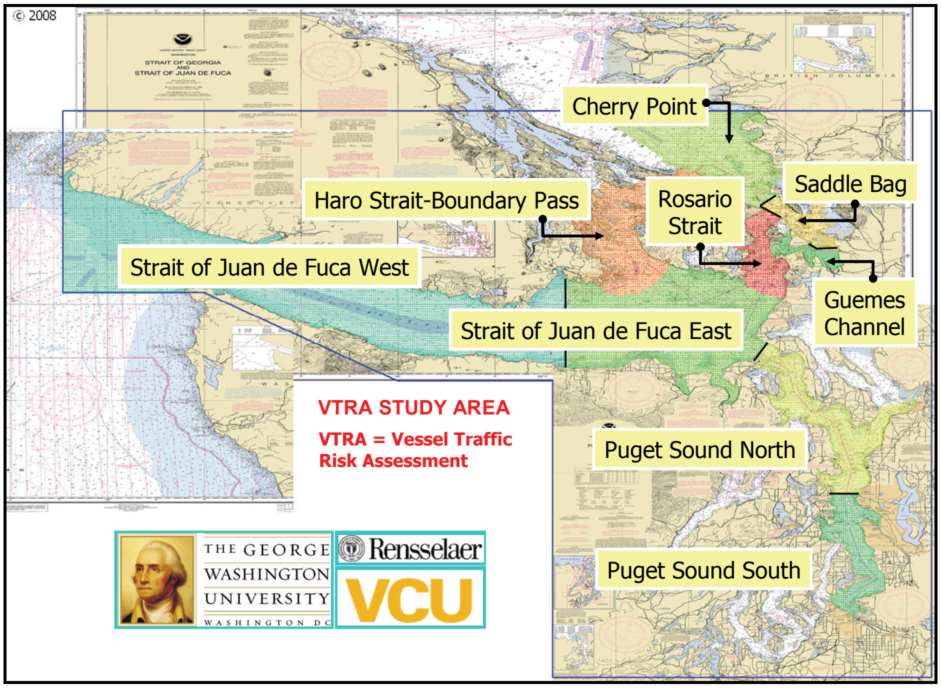


Figure C-17. The Vessel Traffic Risk Assessment (VTRA) study area and the definition of its nine different locations for expert judgment purposes.

Figure C-18 displays all the current stations within the VTRA study area for which we able to produce current tables and other information such as max ebb, max flood and ebb and flood direction parameters. Figure C-18 displays the max ebb and max flood directions and levels for the current stations in the VTRA simulation.

C-6.1.1. Current data and list of current stations.

Information from the various data sources listed in Figure C-18 was reconciled to create this figure. For " the current reference stations": Admiralty Inlet, Deceptions Pass, Gray Harbor, Rosario Strait, San Juan Channel South Entrance, Strait of Juan de Fuca and The Narrows End, current tables were generated for the years 2002-2005 from the WXTIDE Software. These tide tables were cross-checked with those available on the NOAA tides and currents web site. Figure C-19 provides a snapshot view of a section of the tide table for the reference station Rosario Strait. These tables were next electronically transferred into a database format that could be read by the VTRA simulation.

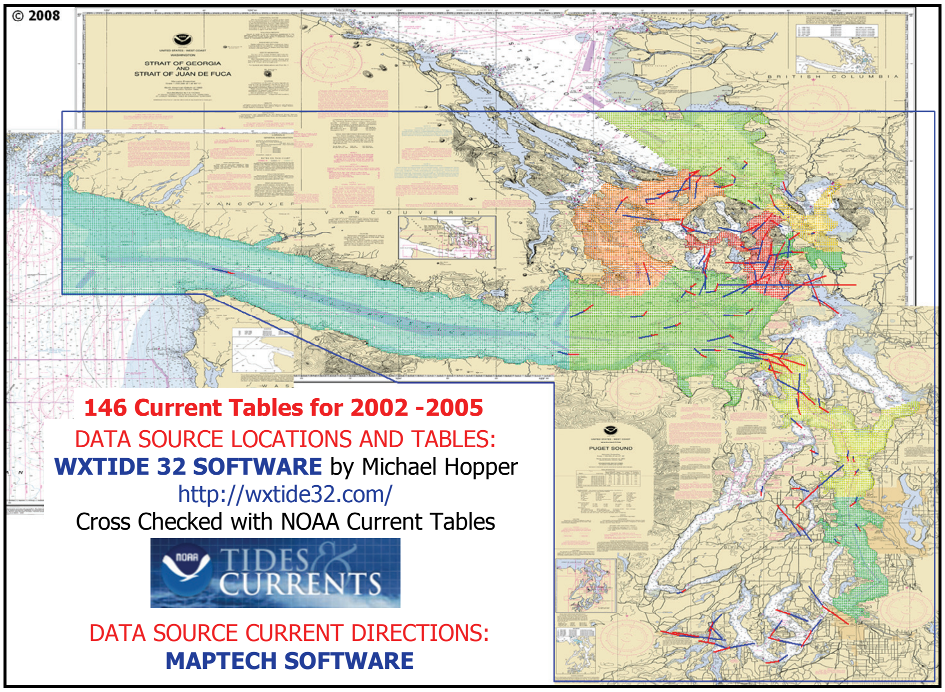


Figure C-18. Geographic locations of 130 current stations in the (VTRA) study area.

```
Rosario Strait, Washington Current
Units are knots, initial timezone is PST
January 2005 low is -3.5kt, high is 2.7kt, range is 6.2kt.
Predicted historical low is -4.8kt, high is 4.0kt, range is 8.8kt.

Sunday      Monday     Tuesday    Wednesday   Thursday   Friday      Saturday

Full 12-26     12-27      12-28      12-29      12-30      12-31      01-01
F0314   2.0 S0032 -0.0 S0105   0.0 S0137   0.0 S0208   0.0 S0240   0.0 S0310   0.0
S0725 -0.0 F0338   2.1 F0404   2.1 F0435   2.2 F0510   2.1 F0547   2.1 F0621   1.9
E0954 -1.0 S0757 -0.0 S0826 -0.0 S0852 -0.0 S0916 -0.0 S0938 -0.0 S0952 -0.0
S1256   0.0 E1023 -1.1 E1056 -1.2 E1132 -1.2 E1213 -1.3 E1257 -1.4 E1338 -1.5
F1347   0.2 S1352   0.0 S1501   0.0 F1605 -0.1 F1657 -0.1 F1747 -0.1 F1839 -0.0
S1443 -0.0 F1431   0.1 F1516   0.0 E2217 -2.5 E2239 -2.2 E2303 -1.9 E2338 -1.5
E2047 -2.9 S1510 -0.0 S1532 -0.0            E2121 -2.8 E2151 -2.7

   01-02    LQtr 01-03     01-04      01-05      01-06      01-07      01-08
S0344   0.0 E0030 -1.0 E0238 -0.6 S0137 -0.0 S0347 -0.0 F0024   1.5 F0109   1.9
F0658   1.7 S0420   0.0 S0459   0.0 E0404 -0.3 E0520 -0.3 S0504 -0.0 S0556 -0.0
S1007 -0.0 F0736   1.4 F0818   1.1 S0548   0.0 S0703   0.0 E0638 -0.3 E0753 -0.5
E1421 -1.7 S1020 -0.0 S1035 -0.0 F0905   0.7 F1001   0.5 S0922   0.0 S1040   0.0
S1857   0.0 E1502 -2.0 E1541 -2.2 S1059 -0.0 S1132 -0.0 F1101   0.4 F1158   0.3
F1933   0.1 S1931   0.0 S2009   0.0 E1621 -2.5 E1705 -2.8 S1215 -0.0 S1306 -0.0
S2011 -0.0 F2033   0.3 F2145   0.5 S2049   0.0 S2131   0.0 E1754 -3.0 E1848 -3.2
           S2200 -0.0            F2314   1.0            S2213   0.0 S2255   0.0
```

Figure C-19. Example section of a tide table generated by the WXTIDE software by Michael Hopper.

C-6.1.2. Overview of current model in the simulation

The currents of the other 123 current stations are derived from the reference stations (see, e.g. the NOAA tides and currents web-site). The parameters to generate these currents for the first 30 stations are specified in Table C-6. The HTTM parameter in this table indicates if the current station's high tide is delayed or not relative to its reference station. The parameters HTHM, and HTMM are the delay or advance times in terms of hours and minutes (for high tide) whereas the HTM is a multiplier of the current station's reference stations' current speed. Similar parameters are displayed for the low tide scenario in Table C-6 as well.

Table C-6. Current data for the first 30 currents stations in the VTRA maritime simulation.

ID	Name	Lat	Long	RS	FD	ED	HTTM	HTHM	HTMM	HTM	LTTM	LTHM	LTMM	LTM	MF	ME
1	Admiralty Head	48.1500	122.700	2	145	25	+	0	03	1.29	+	0	07	1.2	2.1	3.1
2	Admiralty Inlet	48.0333	122.633	2	179	3	+	0	00	1	+	0	00	1	1.6	2.6
3	Agate Pass 1	47.7167	122.550	2	230	32	-	1	00	0.8	+	0	59	0.69	0	0
4	Agate Pass 2	47.7128	122.565	2	216	37	+	0	53	2	+	0	47	1.39	3.3	3.6
5	Alden Point	48.7578	122.980	107	25	185	+	0	26	0.89	+	0	53	1.1	1	2.1
6	Alki Point	47.5755	122.428	2	160	330	+	0	44	0.3	+	0	39	0.2	0.5	0.5
7	Apple Cove Point	47.8167	122.466	2	168	8	+	0	11	0.3	+	0	29	0.3	0.5	0.8
8	Balch Passage	47.1875	122.697	126	296	107	-	1	07	0.4	+	0	40	0.8	1.1	2.2
9	Barnes Island	48.6858	122.788	107	315	140	+	1	20	0.6	+	0	08	0.5	0.6	0.9
10	Bellingham Channel	48.5603	122.663	107	45	185	-	0	08	1.1	+	0	51	1.2	1.2	2.2
11	Blake Island	47.5250	122.499	2	131	326	-	2	37	0.2	+	0	25	0.2	0.3	0.5
12	Boundary Pass	48.6953	123.235	107	41	203	-	0	34	1.6	+	0	02	1.39	0.7	1.6
13	Burrows Bay	48.4628	122.682	107	22	209	+	0	48	0.89	+	0	43	0.2	1	0.4
14	channel	47.4667	122.700	107	304	96	+	0	34	2	+	0	57	0.69	0	0
15	Burrows Island Light	48.4833	122.733	107	15	200	+	0	03	1	+	0	16	1.1	1.1	2.1
16	Bush Point Light	48.0333	122.616	2	144	309	+	0	21	1.1	+	0	35	1.1	1.7	2.9
17	Cattle Point 1	48.4338	122.947	108	340	195	+	0	20	0.3	+	0	01	0.89	0.8	2.4
18	Cattle Point 2	48.4000	123.000	2	46	187	-	0	52	0.4	+	0	42	0.2	0.6	0.4
19	Cattle Point 3	48.3833	123.016	2	120	210	+	1	11	0.6	+	0	44	0.3	0.9	0.9
20	Clark Island	48.7333	122.766	107	335	150	+	1	14	0.6	+	0	02	0.6	0	0
21	Colville Island 1	48.4000	122.816	107	55	235	+	0	31	1	+	0	07	1.2	1.1	2.3
22	Colville Island 2	48.4167	122.783	107	55	215	-	0	14	1.39	+	0	14	1	1.6	1.9
23	Crane Island	48.5895	122.998	108	288	75	+	0	35	0.2	+	0	07	0.1	0.4	0.3
24	Dana Passage	47.1633	122.867	126	249	76	+	0	09	0.5	+	0	12	0.8	1.5	2.2
25	Deception Island 1	48.4197	122.698	107	17	161	+	1	14	0.6	-	1	23	0.5	1.3	1.1
26	Deception Island 2	47.4000	122.700	107	35	210	-	0	04	1.2	-	2	29	0.6	0	0
27	Deception Island 3	48.4125	122.739	107	15	190	-	0	50	0.8	+	0	34	0.69	0.9	1.3
28	Deception Pass	48.4062	122.643	28	90	270	+	0	00	1	+	0	00	1	5.2	6.6
29	Discovery Island 1	48.3833	123.200	2	25	250	+	0	15	0.6	+	0	04	0.89	0	0
30	Discovery Island 2	48.4500	123.150	2	345	170	+	1	03	0.8	+	0	59	0.6	1.3	1.6

C-6.1.3. Representative results of current in the simulation

Tide tables only specify when a current station's high tide, low tide and slack states are occurring and provide the current speeds at these times. To model the current in the VTRA simulation in between the max ebb and max flood stages, a harmonic curve was fitted between these time points. Figure C-20 provides a section of the resulting fitted time series for the reference current station Rosario Strait. Similar time series were generated during the VTRA maritime simulation for the other current stations as well. The current experienced by a particular vessel within the VTRA maritime simulation was determined by looking up the current of its closest current station within the VTRA study area (see Figure C-18 for a geographic depiction of the available current stations within the study area).

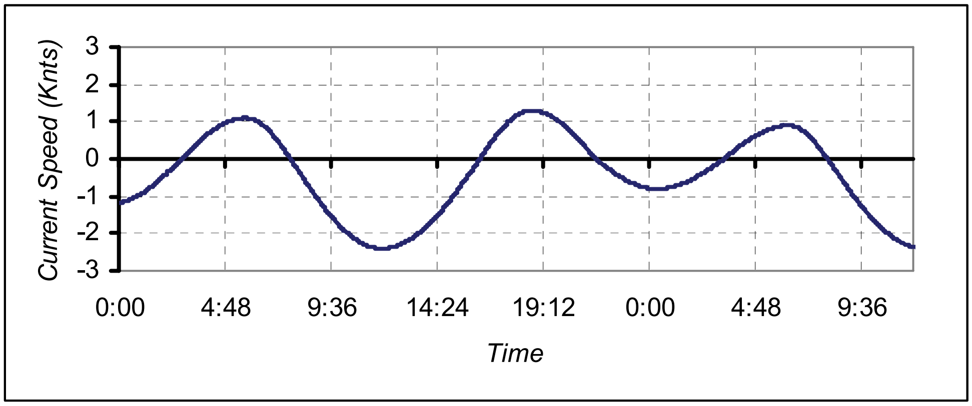


Figure C-20. A time series section of the Rosario Strait reference current station.

C-6.2. Wind Modeling

Figure C-21 provides a geographical depiction of the different weather stations for which various meteorological data was downloaded from the National Climatic Data Center's website. Tables C-7 and C-8 describes this downloaded data in more detail. Table C-7 provides the lat-long coordinates of the 30 weather stations that we queried to simulate weather within the VTRA simulation. Table C-8 details the specific meteorological data that we were able to download from the National Climatic Data Center for these weather stations. In the subsections below we shall further elaborate which weather stations were selected for particular "pieces" of our weather simulation model.

C-6.2.1. NOAA weather station data

Figure C-22 provides a geographical depiction of the weather stations that were used to provide wind speed and wind direction by the hour for the locations within the VTRA study area.

C-6.2.2. Overview of wind modeling

Table C-9 provides an example section of the wind data downloaded from the national climatic datacenter for the Race Rocks Campbell weather station.

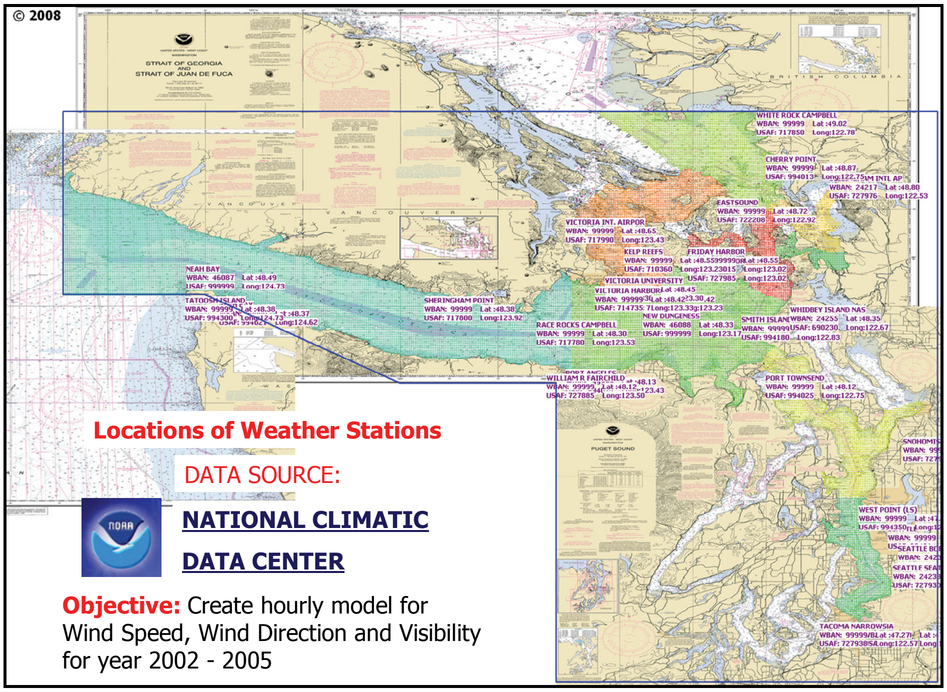


Figure C-21. Geographic locations of weather stations in the (VTRA) study area queried to model hourly behavior of environmental variables.

Table C-7. Geographic locations of thirty weather stations queried from the National Climatic Data Center to model weather in the VTRA maritime simulation.

ID	USAF	WBAN	NAME	CALL	LAT	LONG
1	727976	24217	BELLINGHAM INTL AP	KBLI	48.8	122.533
2	994013	99999	CHERRY POINT	CHYW1	48.867	122.75
3	722208	99999	EASTSOUND	KORS	48.717	122.917
4	727985	99999	FRIDAY HARBOR	KFHR	48.517	123.017
5	994015	99999	FRIDAY HARBOR	FRDW1	48.55	123.017
6	999999	46087	NEAH BAY		48.49	124.73
7	994021	99999	NEAH BAY	NEAW1	48.367	124.617
8	994024	99999	PORT ANGELES	PTAW1	48.133	123.433
9	994025	99999	PORT TOWNSEND	PTWW1	48.117	122.75
10	994014	99999	SEATTLE	EBSW1	47.6	122.333
11	727935	24234	SEATTLE BOEING FIELD	KBFI	47.533	122.3
12	727930	24233	SEATTLE SEATTLE-TACOMA INTL A	KSEA	47.467	122.317
13	994180	99999	SMITH ISLAND	SISW1	48.317	122.833
14	727937	99999	SNOHOMISH CO	KPAE	47.9	122.283
15	994048	99999	TACOMA	TCNW1	47.267	122.417
16	727938	99999	TACOMA NARROWS	KTIW	47.267	122.567
17	994300	99999	TATOOSH ISLAND	TTIW1	48.383	124.733
18	994350	99999	WEST POINT (LS)	WPOW1	47.667	122.433
19	690230	24255	WHIDBEY ISLAND NAS	KNUW	48.35	122.667
20	727885	99999	WILLIAM R FAIRCHILD	KCLM	48.117	123.5
21	710310	99999	DISCOVERY ISLAND		48.417	123.233
22	717780	99999	RACE ROCKS CAMPBELL		48.3	123.533
23	717800	99999	SHERINGHAM POINT		48.383	123.917
24	717990	99999	VICTORIA INT. AIRPOR		48.65	123.433
25	717830	99999	VICTORIA UNIVERSITY		48.45	123.3
26	717850	99999	WHITE ROCK CAMPBELL		49.017	122.783
27	710360	99999	KELP REEFS		48.55	123.233
28	714735	99999	VICTORIA HARBOR		48.417	123.333
29	994070	99999	DESTRUCTION ISLAND		47.667	124.483
30	999999	46088	NEW DUNGENESS		48.33	123.17

Table C-8. Meteorological data downloaded from the National Climatic Data Center for the weather stations specified in Table C-7.

ID	NAME	WS	WD	LAND VIS	DEW	WTMP	PERIOD
1	BELLINGHAM INTL AP	1	1	1	1	0	01-02 12-05
2	CHERRY POINT	0	0	0	0	1	01-05 12-05
3	EASTSOUND	1	1	1	1	0	08-04 12-05
4	FRIDAY HARBOR	1	1	1	1	0	01-02 12-05
5	FRIDAY HARBOR	0	0	0	0	1	04-05 12-05
6	NEAH BAY	1	0	0	1	1	01-04 12-05
7	NEAH BAY	0	0	0	0	1	01-05 12-05
8	PORT ANGELES	0	0	0	0	1	04-05 12-05
9	PORT TOWNSEND	0	0	0	0	1	04-05 12-05
10	SEATTLE	1	1	0	0	1	04-05 12-05
11	SEATTLE BOEING FIELD	1	1	1	1	0	01-04 12-05
12	SEATTLE SEATTLE-TACOMA INTL A	1	1	1	1	0	01-02 12-05
13	SMITH ISLAND	1	1	0	0	0	01-02 12-05
14	SNOHOMISH CO	1	1	1	1	0	01-02 12-05
15	TACOMA	0	0	0	0	1	04-05 12-05
16	TACOMA NARROWS	1	1	1	1	0	01-02 12-05
17	TATOOSH ISLAND	1	1	0	0	0	01-02 12-05
18	WEST POINT (LS)	1	1	0	1	0	01-02 12-05
19	WHIDBEY ISLAND NAS	1	1	1	1	0	01-02 12-05
20	WILLIAM R FAIRCHILD	1	1	1	1	0	01-02 12-05
21	DISCOVERY ISLAND	1	1	0	0	0	12-02 12-05
22	RACE ROCKS CAMPBELL	1	1	0	0	0	01-02 12-05
23	SHERINGHAM POINT	1	1	0	1	0	01-02 12-05
24	VICTORIA INT. AIRPOR	1	1	1	1	0	01-02 12-05
25	VICTORIA UNIVERSITY	1	1	0	1	0	01-02 12-05
26	WHITE ROCK CAMPBELL	1	1	0	1	0	01-02 12-05
27	KELP REEFS	1	1	0	0	0	06-03 12-05
28	VICTORIA HARBOR	1	1	1	1	0	01-02 12-05
29	DESTRUCTION ISLAND	1	1	0	0	0	01-02 12-05
30	NEW DUNGENESS	1	1	0	1	1	07-04 12-05

Table C-9. A section of a downloaded wind data table for the Race Rock Campbell weather station from the National Climatic Data Center.

Date	HrMn	WD	WS
20051010	200	10	3.6
20051010	300	90	2.5
20051010	400	350	0.5
20051010	500	150	2
20051010	600	999	0
20051010	700	40	1
20051010	800	70	3
20051010	900	10	3

Simple because one can download specific meteorological data for a particular weather station for a selected from the National Climatic Data Center does not mean that this data is of a good quality. Please note for example the presence of the observation 999 in Table C-9. This indicates that for that particular hour no observation is available. In the presence of such an observation, the wind of the previous hour is selected to continue for one additional hour.

C-6.2.3. Representative results of wind in the simulation

Wind speeds and directions were replayed utilizing similar downloaded tables as Table C-9 for various selected weather stations. The weather stations in Figure C-22 were primarily selected based on the quality of their data (i.e. based on the absence of long sequences of similar 999 records as displayed in Table C-9) and their location relative to the definition of the different locations within the VTRA study area. For example, Figure C-22 depicts that the West point (LS) weather stations was used to both provide wind speed and wind direction for the Puget Sound North and the Puget Sound South locations.

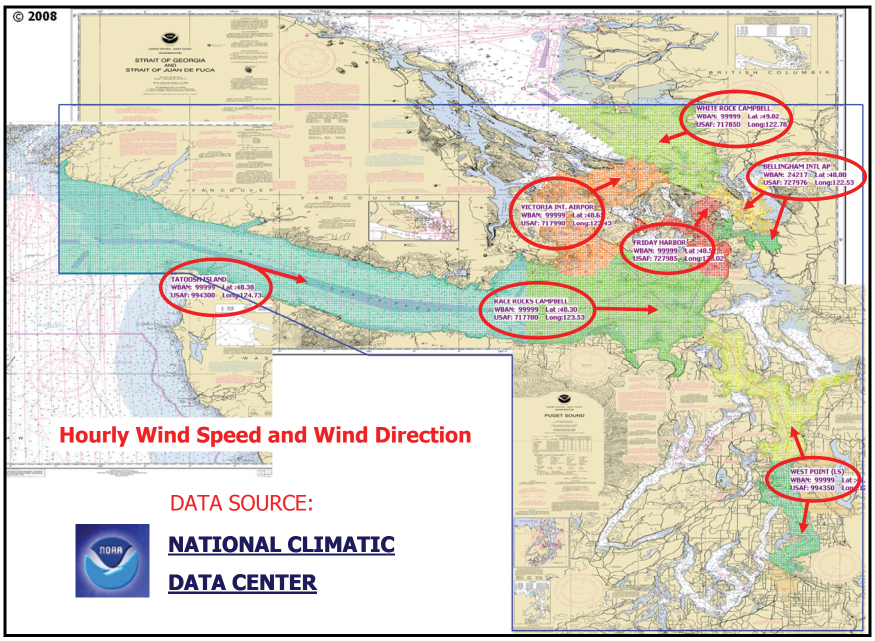
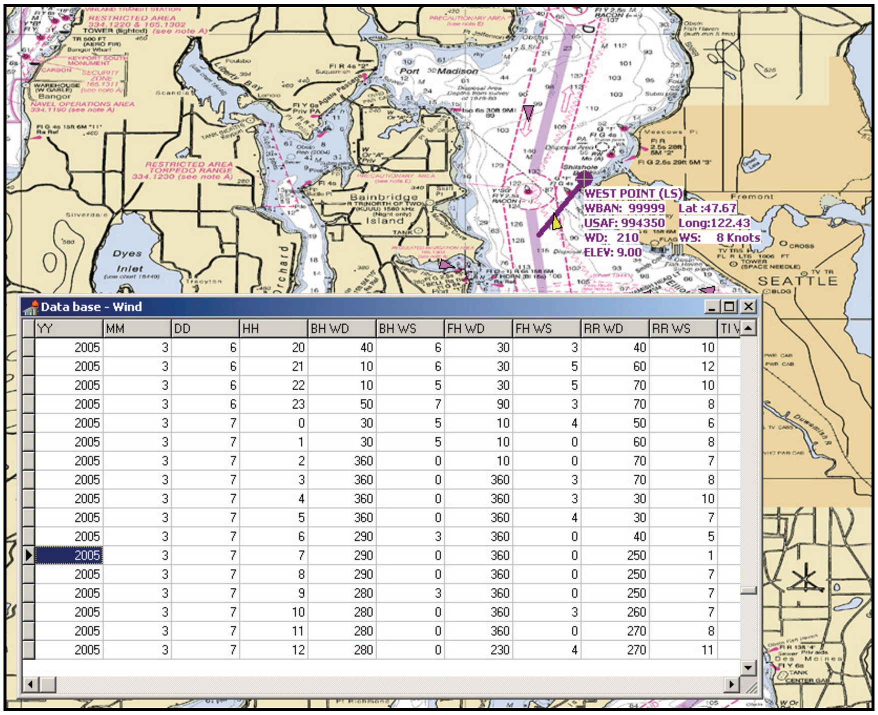


Figure C-22. Geographic locations of weather stations in the VTRA study area queried to model hourly behavior of wind speed and wind direction.

Figure C-23 displays a screenshot of the wind speed and wind direction databases within the VTRA maritime simulation. It also specifically displays the current wind speed and wind direction of the West Point (LS) weather stations. The length of the arrow varies as the wind speed changes and the angle changes according to the angles as specified in wind databases.



YY	MM	DD	HH	BH WD	BH WS	FH WD	FH WS	RR WD	RR WS
2005	3	6	20	40	6	30	3	40	10
2005	3	6	21	10	6	30	5	60	12
2005	3	6	22	10	5	30	5	70	10
2005	3	6	23	50	7	90	3	70	8
2005	3	7	0	30	5	10	4	50	6
2005	3	7	1	30	5	10	0	60	8
2005	3	7	2	360	0	10	0	70	7
2005	3	7	3	360	0	360	3	70	8
2005	3	7	4	360	0	360	3	30	10
2005	3	7	5	360	0	360	4	30	7
2005	3	7	6	290	3	360	0	40	5
2005	3	7	7	290	0	360	0	250	1
2005	3	7	8	290	0	360	0	250	7
2005	3	7	9	280	3	360	0	250	7
2005	3	7	10	280	0	360	3	260	7
2005	3	7	11	280	0	360	0	270	8
2005	3	7	12	280	0	230	4	270	11

Figure C-23. A screen shot of the resulting wind speed and direction database in the VTRA maritime simulation.

C-6.3. Visibility Modeling

Figure C-22 provides a geographical depiction of the weather stations that were used to provide land visibility data by the hour for the locations within the VTRA study area. One observes that the locations of these weather stations coincide with the various airports within the VTRA study area. No electronic data source with hourly land visibility data was available at the entrance of the West Strait of Juan de Fuca. Hence, the land visibility data from the William Fairchild airport had to be used for both the West and East Strait of Juan de Fuca locations.

While certainly land visibility is one of the components that determine bad visibility on the water another type of fog that is modeled within the VTRA maritime simulation is sea fog. Indeed, it is not uncommon to have perfect visibility on land, but fog on the water. Unfortunately, no electronic data repositories are available (to the best of our knowledge) with hourly sea fog data. In the sections below we will further discuss in some detail the specifics of the sea fog visibility model that we implemented within the VTRA simulation model. This model had previously been used in the Washington State Ferry Risk Assessment (Van Dorp et. al (2001)) and in the San Francisco Bay Exposure Assessment (Merrick et. al (2003). For convenience these journal papers are attached as sub-appendices.

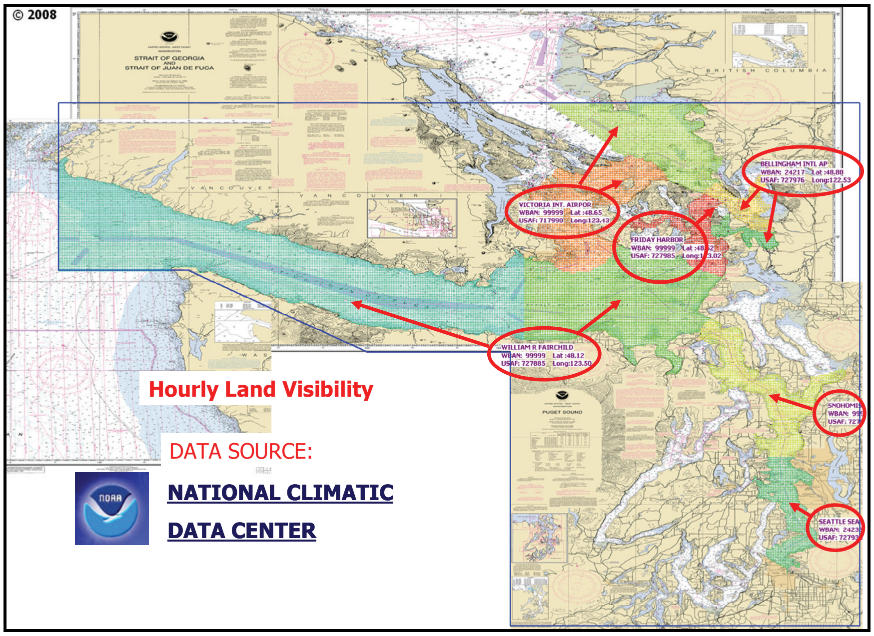


Figure C-24. Geographic locations of weather stations in the VTRA study area queried to model hourly behavior of land visibility.

Perhaps with the advance of AIS on board of vessels, the vessels within a specific area could serve as a future data source for collecting sea fog data. Indeed, under foggy conditions in a particular area vessel are required to operate their fog signals. This data could be transmitted to an AIS datacenter at the same time when its location is transmitted. At this time, however, we have to rely on the sea fog visibility model discussed below.

C-6.3.1. Overview of visibility modeling.

Our sea visibility model is a meteorological model taken from Sanderson (1982) and is explained in more detail in Figure C-25. The model specified the occurrence of sea fog when the difference between the dew point temperature and the water temperature reaches a certain threshold Δ. The model states that when Δ is between 0 and 2 degrees Celsius patches of fog develop and when Δ is larger than two degrees Celcius a dense fog develops.

This phenomenon requires that wind do not exceed 3 Beaufort. We utilized the information from the wind model discussed in the previous section to apply the 3 Beaufort threshold.

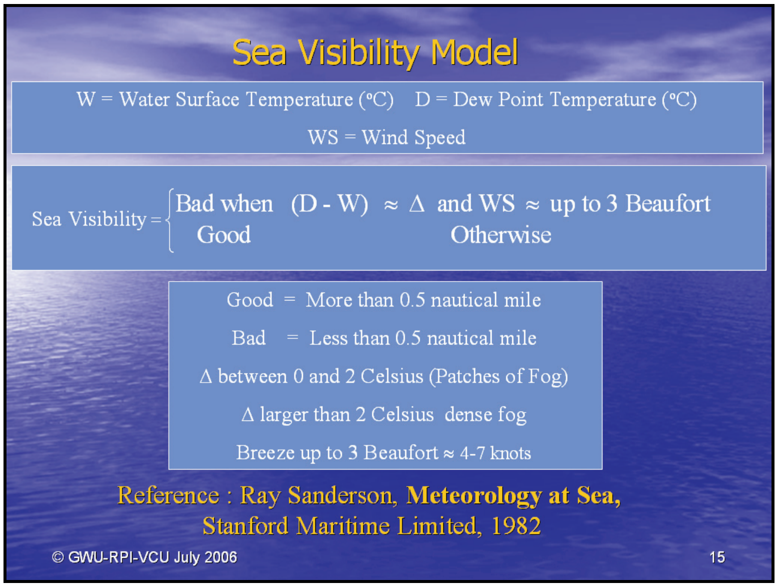


Figure C-25. Sea visibility model used in the VTRA maritime simulation.

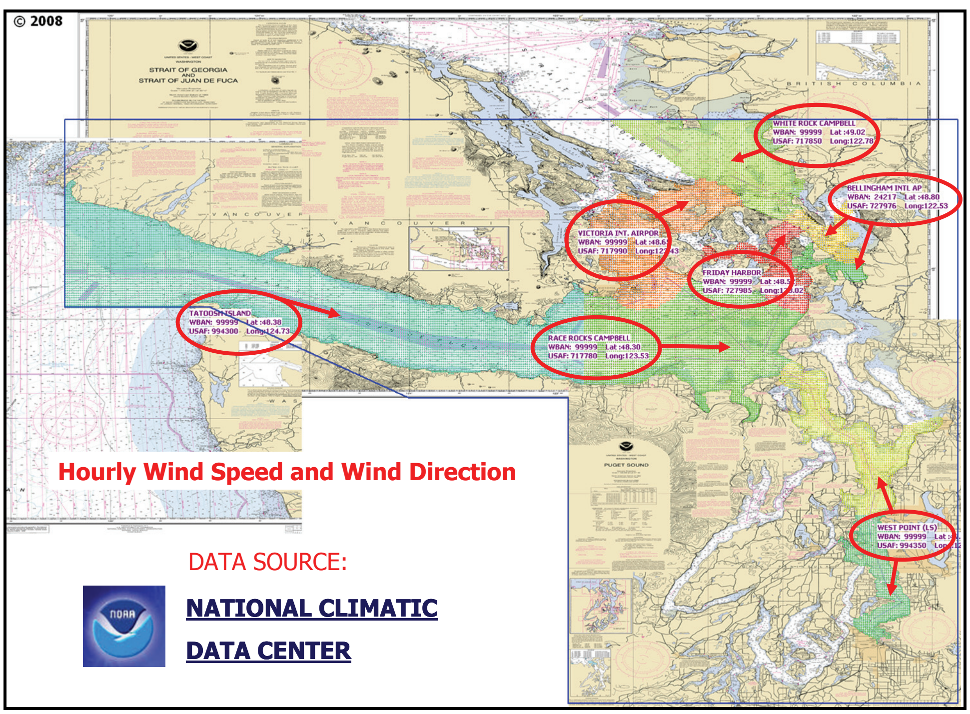


Figure C-26. Geographic locations of weather stations in the VTRA study area queried with hourly dew point data.

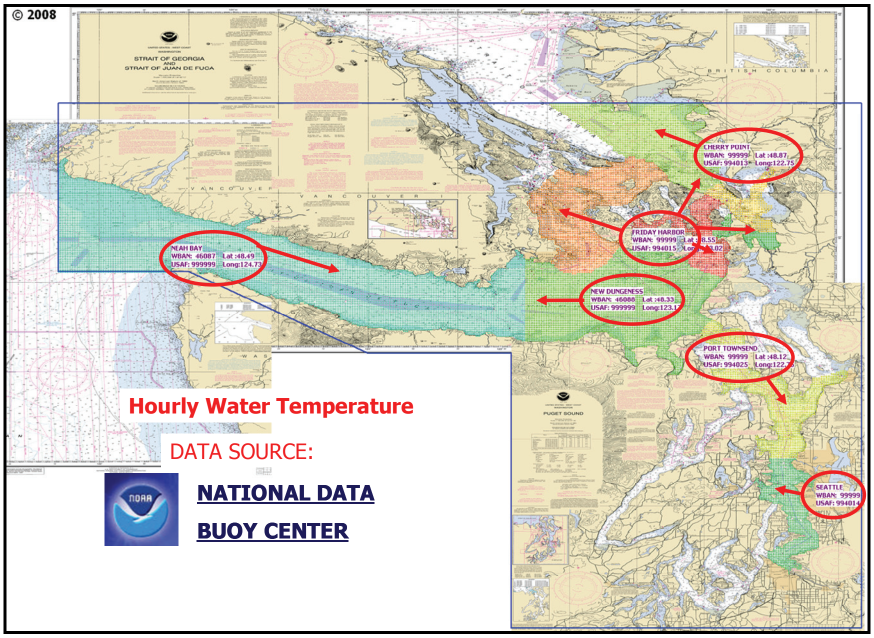


Figure C-27. Geographic locations of weather stations in the VTRA study area queried with hourly water temperature data.

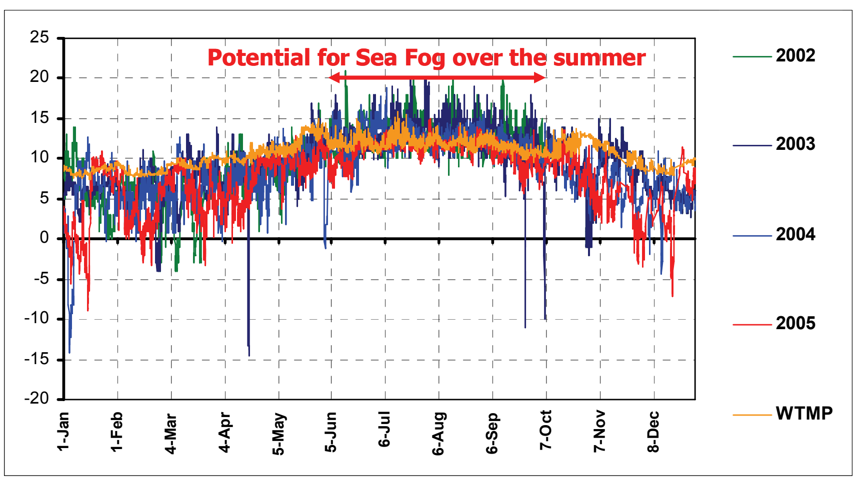


Figure C-28. Hourly time series of water temperature and dew point for the West Strait of Juan de Fuca location in Figure C-17.

Figure C-26 provides a graphic of those weather stations for which were able to obtain hourly dew point data from the National Climatic Data Center. Figure C-27 provides a graphic of those weather stations for which were able to obtain hourly water temperature data from the National Climatic Data Center. Please note that some of these weather stations coincide with the NOAA weather buoys. Combining the information from Figures C-26 and C-27 we obtain the hourly time series for the West Strait of Juan de Fuca location as displayed in Figure C-17.

Unfortunately, we were only able to obtain one full year of water temperature data. Also note when comparing Figures C-26 and Figure C-27 that these observation are not taken at the same location. Hence, rather than implementing the threshold parameter Δ settings from Figure C-25 literally this parameter was used as a calibration parameter to ensure an average set number of bad visibility days in the locations defined in Figure C-17. Prior to this calibration process the land visibility information from Figure C-24 was integrated with the sea visibility model. The land visibility data contains an hourly distance of visibility.

Figure C-29 provides the anecdotal information that we were able to obtain from the US Coast pilot publication (2006 edition). Figure C-30 provides similar information that we were able to obtain for the East Strait of Juan de Fuca. Figure C-29 and Figure C-30 detail that we were able to calibrate at 0.75 miles to an average of 54 days (as opposed to the 55 days specified by the US Coast Pilot) for the West Strait of Juan de Fuca location and 35 days for the East Strait of Juan de Fuca location. This results next in an average of 50 days of bad visibility in the West Strait of Juan de Fuca at 0.5 miles and an average of 31 days of bad visibility at the East Strait of Juan de Fuca. The 0.5 miles threshold is used in the expert judgment elicitation for accident probabilities (see Appendix D).

After calibration of our visibility model, Figure C-31 displays the resulting percentage of time bad visibility by the hour for the West Strait of Juan de Fuca. Figure C-32 displays the same information for the East Strait of Juan de Fuca. Please note the presence of primarily a channel sea fog phenomenon in the early morning hours and early evening hours in the months of June, July, August and to a lesser extent in the month of September in the West Strait of Juan Fuca location. A similar channel fog phenomenon followed from our sea visibility model for the Golden Gate Bridge location in the San Francisco Bay exposure assessment (see, Merrick et. al 2003). The bad visibility within these months during the day time is primarily a land visibility phenomenon.

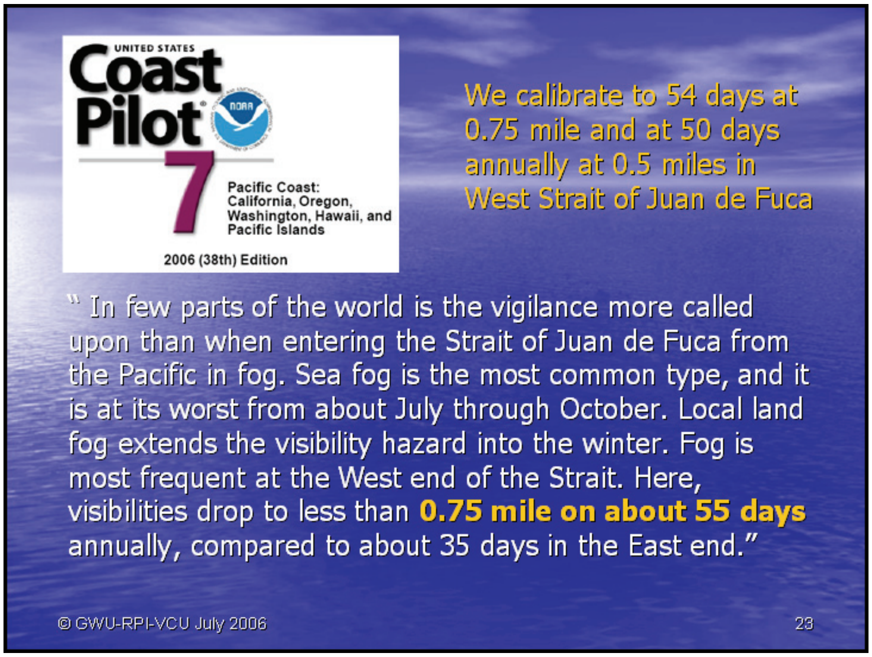


Figure C-29. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days at the West Strait of Juan de Fuca.

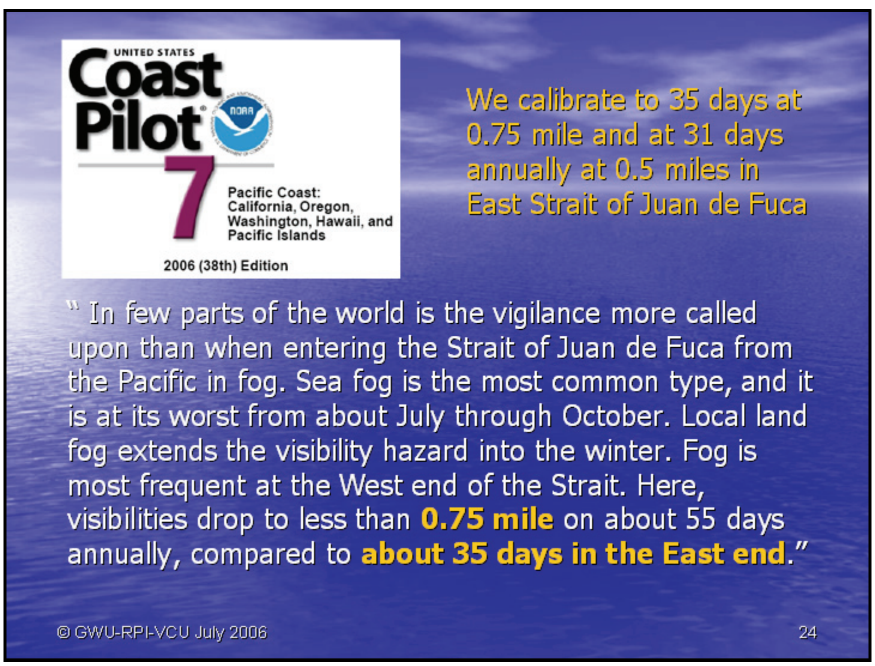


Figure C-30. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days at the East Strait of Juan de Fuca.

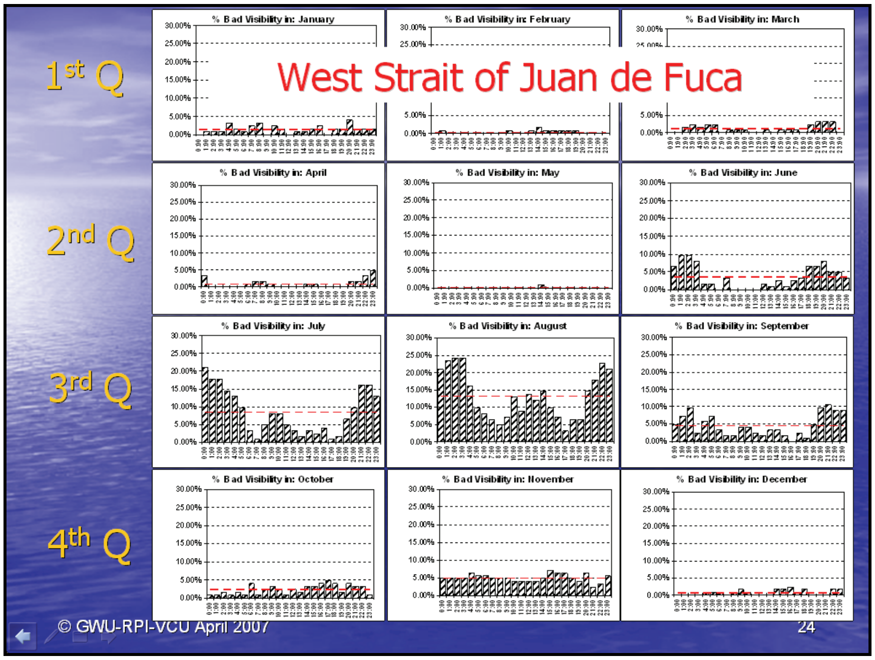


Figure C-31. Hourly modeled percentage of time bad visibility by month in West Strait of Juan de Fuca.

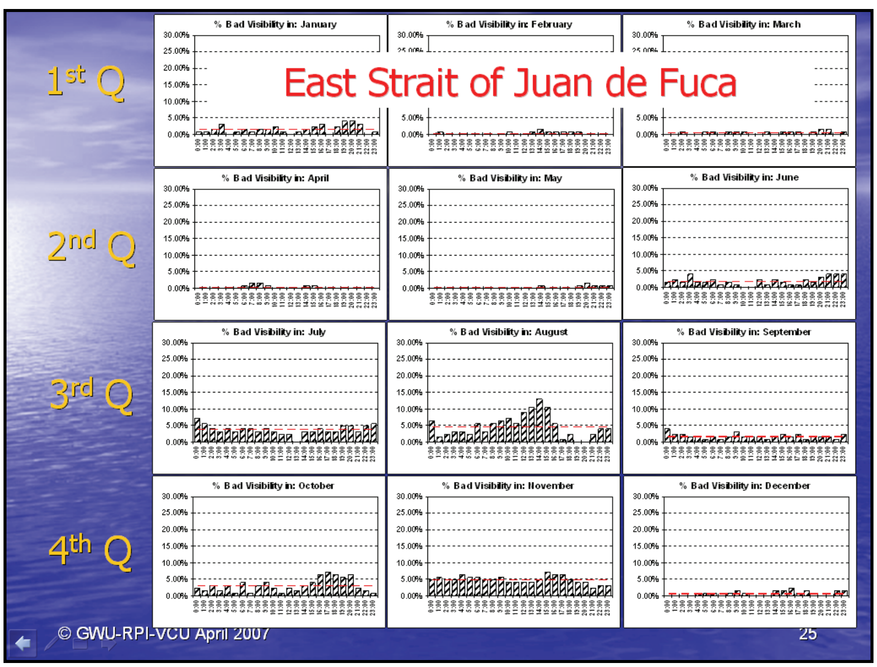


Figure C-32. Hourly modeled percentage of time bad visibility by month in East Strait of Juan de Fuca.

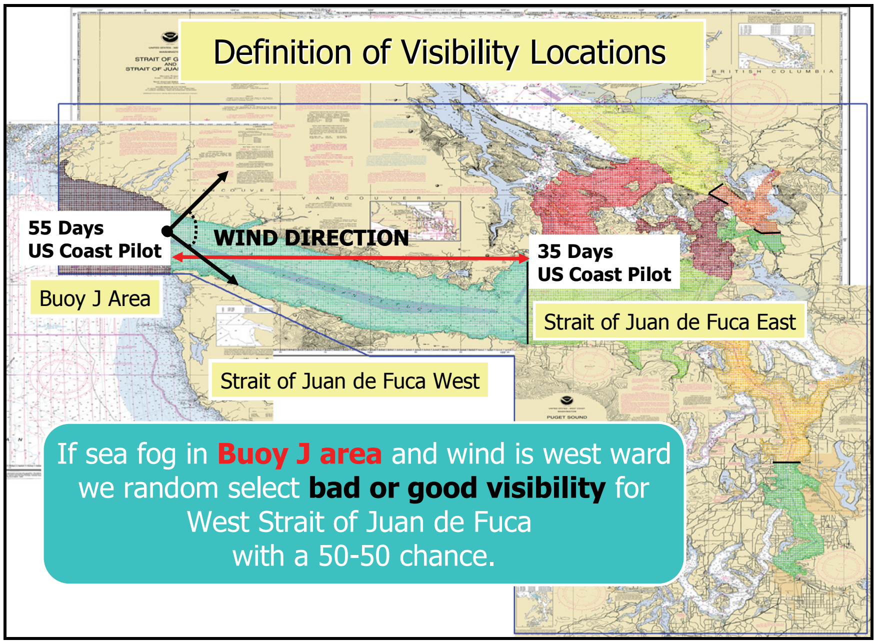


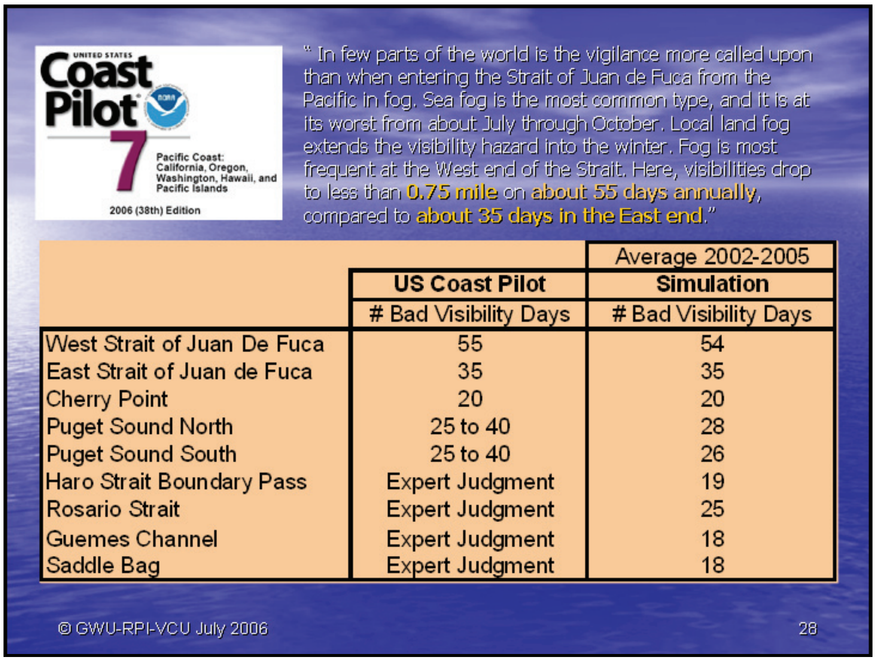
Figure C-33. Modeling a channel fog phenomenon in the Strait of Juan de Fuca West.

We observe from Figure C-32 a less pronounces see channel fog phenomenon for the East Strait of Juan de Fuca (most pronounced in the month of July).

Given the large geographical area that the modeled West Strait of Juan de Fuca location in Figure C-17 encompasses, we have modeled a more smooth transition between the 54 and 35 days for the West Strait of Juan de Fuca and East Strait of Juan de Fuca as specified by the US Coast Pilot. Given that we obtained water temperature data to the extreme west end of the Strait of Juan de Fuca we added a visibility location "Buoy J" as depicted in Figure C-33, we applied the 55 days of bad visibility from the US Coast Pilot to this location. To further model a channel fog phenomenon, we sample with a 50-50 chance bad visibility with the visibility location Strait of Juan de Fuca West (as displayed in Figure C-33) if the wind is eastward into the West Strait of Juan de Fuca (as depicted in Figure C-33) and bad visibility is present in the Buoy J location depicted in Figure C-33.

The US Coast Pilot (2006 edition) also provided a range for the number of bad visibility days experiences typically experienced in the Puget Sound North and South. Since it also states that visibility in the Puget Sound North and South is less prevalent as in the Strait of Juan de

Fuca, it was decided to calibrate our visibility models for these locations towards the lower bounds of the specified range from the US Coast Pilot. Unfortunately, no anecdotal information in terms of number of annual bad visibility days was provided by the US Coast Pilot for the location definitions Haro-Strait-Boundary pass, Rosario Strait, Guemes Channel, and Saddle Bag in Figure C-17. To arrive at the number of days to which the visibility model was calibrated we utilized expert judgment elicitation. Figure C-34 provides the number of bad visibility days that followed after calibration to the expert judgment. This process is described in more detail in the next section.



	US Coast Pilot	Average 2002-2005 Simulation
	# Bad Visibility Days	# Bad Visibility Days
West Strait of Juan De Fuca	55	54
East Strait of Juan de Fuca	35	35
Cherry Point	20	20
Puget Sound North	25 to 40	28
Puget Sound South	25 to 40	26
Haro Strait Boundary Pass	Expert Judgment	19
Rosario Strait	Expert Judgment	25
Guemes Channel	Expert Judgment	18
Saddle Bag	Expert Judgment	18

Figure C-34. Anecdotal data from the US Coast Pilot (2006 edition) regarding the average number of bad visibility days for the Puget Sound South and North.

C-6.3.2. Calibrating the visibility model with expert judgments.

We were extremely fortunate that in November 2006 the Puget Sound Harbor Safety committee agreed to provide us a platform to present interim results of the VTRA study and ask for feedback from the Puget Sound maritime community. This platform and the close relationship between the Puget Sound maritime community, were instrumental in obtaining access to experts and the expert participation that we received. We were able to hold our first expert judgment elicitation session one month after the introduction to the Puget Sound

Harbor Safety committee. Invitations to the expert judgment elicitation sessions were sent out initially by the US Coast Guard and later on by the Puget Sound Harbor Safety committee. None of the experts personally benefited from participating in the expert judgment elicitation. They donated their time for the enhancement of the safety levels in their maritime domain and they should be commended for it. Each expert judgment elicitation session consisted of a morning and afternoon session.

Two elicitation sessions were held that included visibility questionnaires; one in December 2006 and one in February 2007. The elicitation sessions were held at the US Coast Guard Seattle Sector VTS building. In total 20 experts responded to these questionnaires. The cumulative years of experience within the VTRA study area of these experts equals 513. Table C-10 further describes the experience by the type of expert.

As part of our Institutional Review Board procedure regarding research involving human subjects, it is a requirement that the expert remains anonymous. However, the experts were asked to provide their job title and number of years of sailing experience (see Figure D-1) in the VTRA area (although they were not forced to provide this information to participate in the survey). It was explained to the experts that every effort will be made to keep their provided information confidential. There were instructed that if any of the questions they were asked as part of this study made them feel uncomfortable they could refuse to answer that question.

Table C-10. Experience of experts in the VTRA Study area that participated in the visibility expert judgment elicitation sessions.

5 QUESTIONNAIRES	EXPERTS - Numbers indicate years sailing experience in VTRA Study area	CUMULATIVE EXPERIENCE (YRS)	SESSIONS
Visibility Pair Wise Comparison	7 PILOTS (42,34,32,25,16,16)	186	Dec-06
	6 TUG OPERATORS (39, 30, 30, 30, 15, 12)	156	Feb-07
	4 FERRY OPERATORS (31, 30, 25, 8)	94	
	2 PORT CAPTAINS (27, 25)	52	
	1 VTS WATCH (25)	25	
TOTAL	20 Experts	513	2 Sessions

The objective of the visibility elicitation sessions is to obtain relative percentages of time that mariners have to operate their fog signals in the locations: East Strait of Juan de Fuca, Haro-

Stait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag as per the location definitions in Figure C-17. Figure C-17 was provided to the experts as an explanation of the locations in the introduction of the visibility questionnaires. The location East –Strait of Juan de Fuca was included within the visibility questions to allow for calibration between the visibility modeling in the previous sections and the expert judgment results.

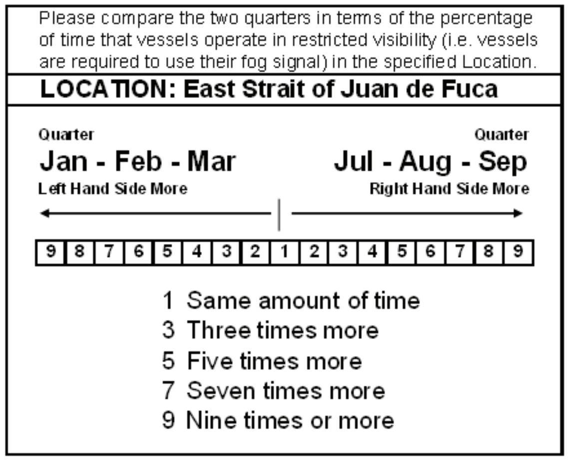


Figure C-35. Example question from East Strait of Juan de Fuca visibility pair wise comparison questionnaire.

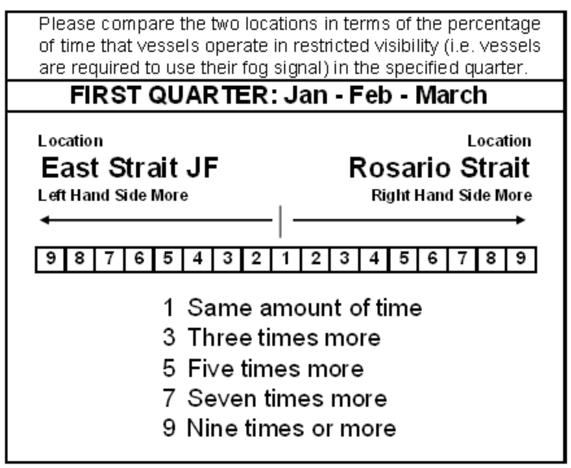


Figure C-36. Example question from Location visibility pair wise comparison questionnaire by quarter.

During one visibility questionnaire elicitation session and expert responded to 5 separate questionnaires. One questionnaire consisted of 6 pair wise comparison question wherein an expert was asked to compare one quarter of the year to another quarter of the year for the East Strait of Juan de Fuca location. Figure C-35 above displays one of the questions in this questionnaire. The four other questionnaires involved pair wise comparisons of locations, one for each quarter. Since these questionnaires involved a total of five locations each questionnaire consisted of 10 questions. Figure C-36 above displays an example question of such a questionnaire for the first quarter of the year.

From the responses of the East Strait of Juan de Fuca questionnaires we can evaluate for each expert the relative multiplier that one quarter of the year for the East Strait of Juan de Fuca has more or less frequent bad visibility than another quarter. From the location questionnaires we can evaluate for each expert the relative multiplier that one location has more of less frequency bad visibility than another location. The responses of an individual expert are compared to an individual expert at random. A statistical hypothesis test involving a consistency index (similar to the Analytical Hierarchy Process (AHP) methodology; see Foreman and Selly (2002)) was formulated such that there was only a 5% chance that a random responding expert would have a lower consistency index. Lower consistency index values are better than higher ones. An expert's response was discarded if a random responding expert had a higher than 5% chance of obtaining a consistency index lower than that of the individual expert. Expert that were retained by applying the rule above were deemed consistent relative to a random responding expert.

The multiplicative weights amongst the remaining consistent expert were averaged using the geometric mean. Summary results of the by quarter questionnaire for the East Strait of Juan de Fuca location are displayed in Figure C-37. The green line represents the results that followed for the East Strait of Juan de Fuca location from the sea/land visibility model discussed in more detail in the previous section. The red line indicates the results for the experts that participated in the December 2006 elicitation session and the blue one indicates the results of those experts that participated in the February 2007 elicitation session, after calibrating the overall average of the expert responses to the overall average of the sea/land visibility model. Please note, the remarkable agreement of both groups of experts relative to the results of our sea/land visibility model discussed in the previous sections. Also note remarkable agreement between both groups of experts. Both display an over estimation in the first and third quarters of the year and an under estimation during the fourth quarter of the year (relative to our sea/land visibility model).

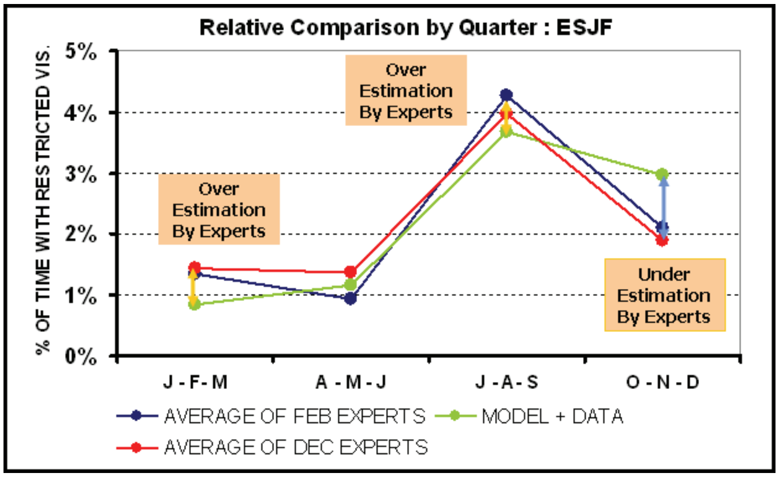


Figure C-37. Expert judgment visibility elicitation results by quarter for the East Strait of Juan de Fuca

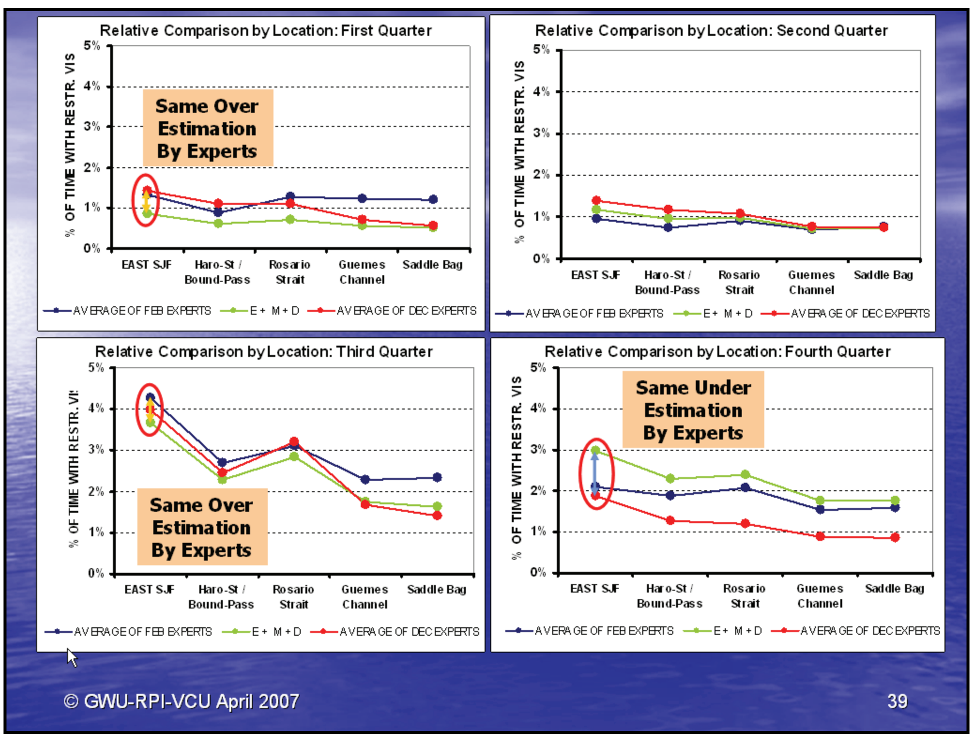


Figure C-38. Expert judgment visibility elicitation results by Location

Figure C-38 summarized the results of the four pair wise comparison questionnaires by location. The red line indicates the results for the experts that participated in the December 2006 elicitation session and the blue one indicates the results of those experts that participated in the February 2007 elicitation session. Please note again the agreement amongst the December experts and the February experts, especially during the third quarter of the year. To arrive at the percentage of time of bad visibility for the locations Haro-Strait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag we used the percentages time of bad visibility for the East Strait of Juan De Fuca and extrapolated to the other locations following the trend lines that we obtained from the December 2006 and February 2007 expert judgment results. The green lines in Figure C-38 summarize these results by quarter and are thus obtained though a combination of modeling, data and expert judgment.

The percentages from Figure C-38 in turn are used to calibrate the sea/land visibility model discussed in the previous section to arrive an hourly time series of bad/good visibility for the locations Haro-Strait/Boundary Pass, Rosario Strait, Guemes Channel and Saddle Bag. The resulting number of bad visibility days per year (defined as a day with at least two hours of bad visibility) for each of these locations are provided in Figure C-34; 25 for Rosario Strait, 19 for Haro-Strait/Boundary Pass, and 18 for both Guemes Chanel and Saddle Bag.

C-6.3.3. Summary results of visibility in the VTRA maritime simulation.

Figure C-39 and Figure C-40 summarize the results of our bad visibility modeling by the different locations as defined by Figures C-17 and C-33. A histogram in these figures provides the number of bad visibility days (defined as one day with at least two hours of bad visibility) by month for a specific location. The locations Buoy J, East and West Strait of Juan de Fuca and Rosario Strait summarized in Figure C-19 display primarily a sea fog phenomenon during the months of June, July and August. The other locations summarized in Figure C-40 display primarily a land fog phenomenon primarily during the months of September through January. Overall a lesser number of bad visibility days seems to be observed during the months of February through.

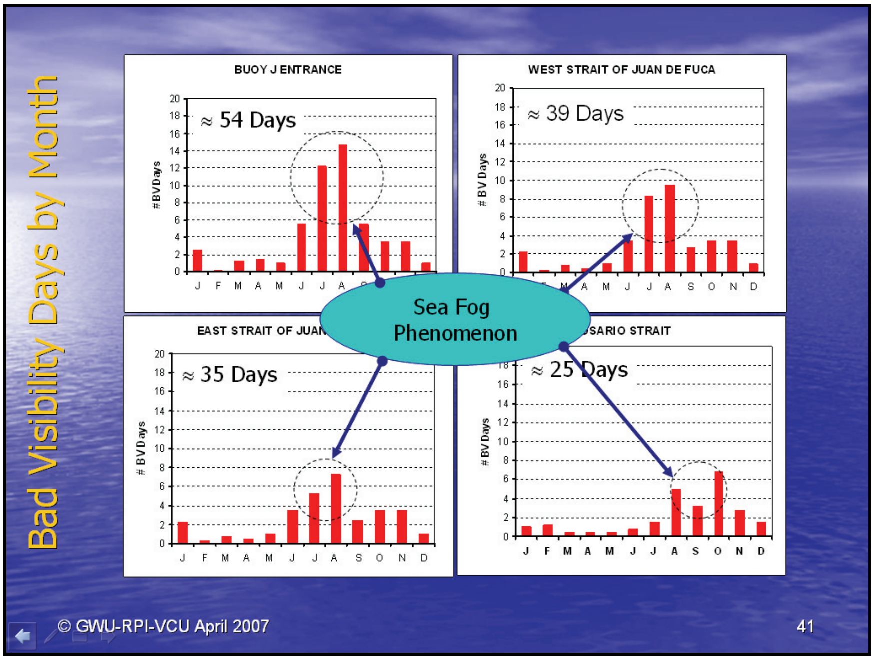


Figure C-39. Summary bad visibility results by month for: Buoy J entrance, West Strait of Juan de Fuca, East Strait of Juan de Fuca and Rosario Strait as defined by Figures C-33 and Figure C-17 for Rosario Strait.

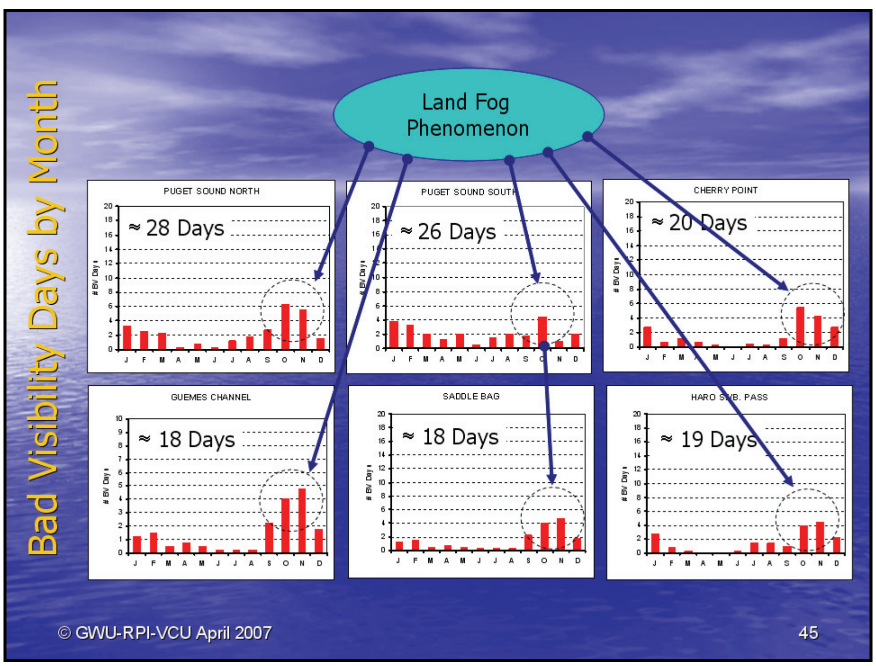


Figure C-40. Summary bad visibility results by month for: Puget Sound North and South, Cherry Point, Guemes Channel, Saddle Bag and Haro-Strait/Boundary Pass as defined by Figure C-17.

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